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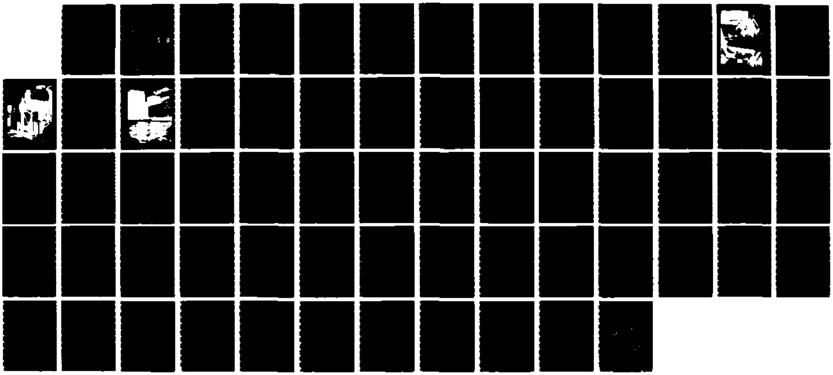

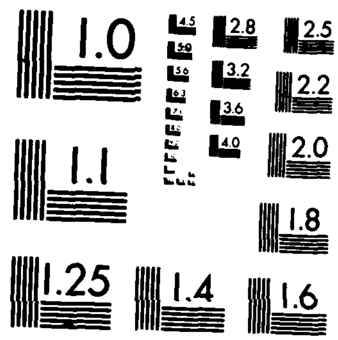

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CRC Report No. 547

CRC CROSS CORRELATION AIRCRAFT ENGINE EMISSION TEST PROGRAM

AD-A173 825

August 1986

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CRC CROSS CORRELATION AIRCRAFT ENGINE EMISSION TEST PROGRAM

(CRC PROJECT No. CA-41-65)

Prepared by the

Analysis Panel

of the

CRC Study Group on Aircraft Exhaust

August 1986

Aviation Fuel, Lubricant and Equipment Research Committee

of the

Coordinating Research Council, Inc.

ABSTRACT

During the period from October 1978 to March 1979, the CRC sponsored a test program to compare the performance of aircraft emission measurement systems. The tests were conducted at the FAA's National Aviation Facilities Experimental Center, ~~(NAFEC),~~ Atlantic City, ~~New Jersey~~. N.J. This report details the results of an analysis of the secured cross-correlation emissions data taken over ~~a period of~~ five weeks by seven participants. Results ~~indicate that~~ the participant-to-participant variability of the gaseous pollutants ~~were:~~

±2S/Avg.-%	of	CO	CO_2	THC	and NO_x
Low and high	Low Power	-	6.5	-	11.9
Concentration	High Power	24.9	-	16.0	-
High	Low ~~Power~~ or	3.7	-	7.5	-
Concentration	High Power	-	5.4	-	6.1

Results for smoke indicate additional development effort is required to secure repeatable smoke data among participants. The smoke analysis was also limited by the small amount of data and the high levels which are no longer typical of current engine emission control technology.

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I. INTRODUCTION AND BACKGROUND

In order to meet a growing need to determine the degree of correlation between aircraft gas turbine emission and smoke measurements made by various test facilities, the Coordinating Research Council, Inc. (CRC) made a request to the Federal Aviation Administration (FAA) to conduct a cooperative emissions testing program. The FAA accepted the responsibility and agreed to host the testing program at the National Aviation Facilities Experimental Center (NAFEC), now the FAA Technical Center, near Atlantic City, New Jersey.

Several organizations were invited to participate, but it was found that some of them were using stationary instrumentation systems which could not be moved to Atlantic City. The program was then divided into two phases. Phase I was to be conducted at Atlantic City for mobile or transportable emissions measurements systems. Phase II would correlate results from stationary or non-transportable systems, and would be conducted at the facilities of the four participants in this phase. The FAA would send one of their mobile emissions research facilities (MERF) to each of the locations to provide the reference measurements in each case. The Phase I work took place between October 1978 and March 1979. The Phase II work was done between June and August 1979.

A third phase was conducted under CRC scrutiny in the United Kingdom. The National Gas Turbine Establishment (now the Royal Aircraft Establishment) and Rolls-Royce carried out a two-week program at Derby, England, in May 1979.

This report will discuss only the work conducted under Phase I. The results of Phase II, and of the British program are the basis of separate reports.

The CRC provided a Test Coordinator, Mr. E. F. Marshall, to handle the scheduling and data collection, and to oversee the subsequent analysis of results. The CRC Test Coordinator was present during the Phase I and Phase II testing and also during the British testing program.

The data from Phase I were entered into a computer program by the FAA and several standard statistical calculations were performed. The results of this work[1,2] are voluminous and are available for inspection at the CRC office. In this report, the results are analyzed and reported in accordance with the specific test program objectives.

Membership of the CRC Aviation Study Group on Aircraft Exhaust, which was responsible for overseeing the program, is listed in Appendix A.

II. TEST OBJECTIVES

The major objectives of the FAA test program were as follows:

1. To establish a cross-correlation of government and engine manufacturers' smoke and gaseous emissions measurement systems operating in a normal test configuration.

2. To determine the typical variability observed between testing groups, or participants, in a normal test configuration while sampling on an actual turbine engine.

3. To estimate the precision errors for the participants and to evaluate the effect of that precision error on the observed variability.

4. To estimate the bias introduced into emissions measurements by span gases and to ensure that corrections for span gases are available.

In this report, these objectives are addressed for the Phase I testing at NAFEC only. The variability reported is carefully restricted to the test objective cited. Little attention is paid to assessing reasons for the observed variability.

III. PARTICIPANTS

Table I lists the participants in this cross-correlation test program. They were on-site according to the schedule shown in Table II-A. Note that Table II-A also outlines the data used when all participants' data for all five weeks were included in the full analysis. Table II-B outlines the data used when only six participants and only four weeks' data were included in the analysis. Table II-B shows the data used in the "modified" analysis (without Participant 7). The main body of this report deals with the modified analysis dictated by excessive variability found in the data from Participant 7. It should be noted that although all participants are named in Table I, they are not listed in the same order as Participant Number. This was done to preserve the anonymity of the data.

TABLE I

LIST OF TEST PARTICIPANTS

Pratt & Whitney - (E. Hartford, Connecticut)

General Electric - (Cincinnati, Ohio)

National Gas Turbine Establishment (NGTE) - (England)

U.S. Naval Air Propulsion Center (NAPC) - (Trenton, New Jersey)

FAA (MERF1) - (Atlantic City, New Jersey)

FAA (MERF2) - (Atlantic City, New Jersey)

FAA (Console) - (Atlantic City, New Jersey)

TABLE II-A

PARTICIPANTS INCLUDED IN FULL ANALYSIS
(All Participants / 5 Weeks' Data)

Participant:	1	2	3	4	5	6	7
Week 1	X	X	X	X			
Week 2	X		X	X	X		
Week 3	X		X		X	X	
Week 4	X		X			X	X
Week 5	X	X	X				X

TABLE II-B

PARTICIPANTS INCLUDED IN MODIFIED ANALYSIS
(All Participants Except Number 7 / 4 Weeks' Data)

Participant:	1	2	3	4	5	6
Week 1	X	X	X	X		
Week 2	X		X	X	X	
Week 3	X		X		X	X
Week 4	X		X			X

IV. TEST SETUP AND EQUIPMENT

A. Emission Source and Sampling System

A mixed flow Pratt and Whitney TF-30-P1 turbofan engine installed in the NAFEC test facility was used as the emissions source for the Phase I cross-correlation program. The engine was modified by removing the afterburner assembly and installing a fixed area exhaust nozzle. This engine incorporated a front fan having a bypass-to-engine airflow ratio of approximately 1.09 to 1, with the fan air diverted through an annular duct forming the outer shell of the engine. The bypass air was mixed with the core airflow downstream of the turbine and the mixed flow exited through the exhaust nozzle. The compressor pressure ratio is about 16 to 1, and the engine thrust rating was 11,500 pounds. Installation of the engine for the NAFEC test program is shown in Figure 1.

Two single-point emissions sampling probes were installed at the exit plane of the exhaust nozzle. One probe was located two inches from the engine centerline where the emissions concentrations were high. The other probe was located ten inches from the engine centerline in an area of low concentration. The probes were referred to as the "high" and "low" probes. Probe locations are shown in Figures 2 and 3.

Each probe was sized to provide enough sample for four emissions systems operating simultaneously. Only one probe was used at a time. The flow from the probe was directed into a heated distribution chamber. Four exit ports from the distribution chamber provided flow to the four instrumentation systems in use at the same time. Any excess flow was spilled overboard at the distribution chamber. No attempt was made to obtain a "representative sample". The objective was to provide a steady source of identical gas samples to the four separate measurement systems. A check of the port-to-port consistency of the sample was made by the FAA prior to the cross-correlation exercise and was found to be satisfactory. The exit ports from the distribution chamber were numbered from 1 through 4. This number was referred to as the "port number" in the data tabulations. The low concentration probe was referred to as "Probe 1" and the high concentration probe was "Probe 2".

Each participant provided his own heated sample line from the distribution chamber to the instruments. Sample lines were heated to approximately 300°F to conform with existing SAE practice (SAE ARP 1256)[3].

Fig. 1

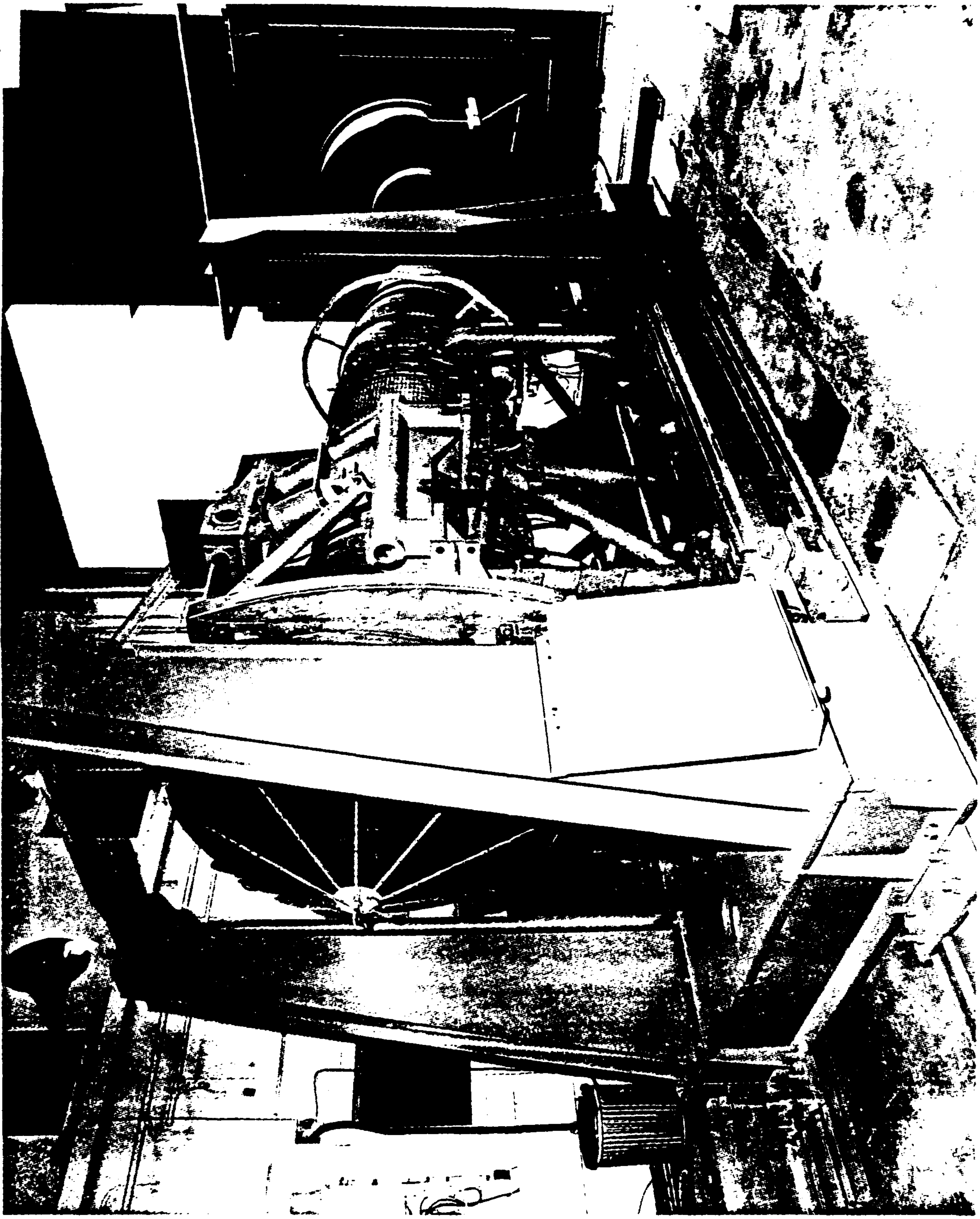


FIGURE 1. ENGINE INSTALLATION AT NAFEC

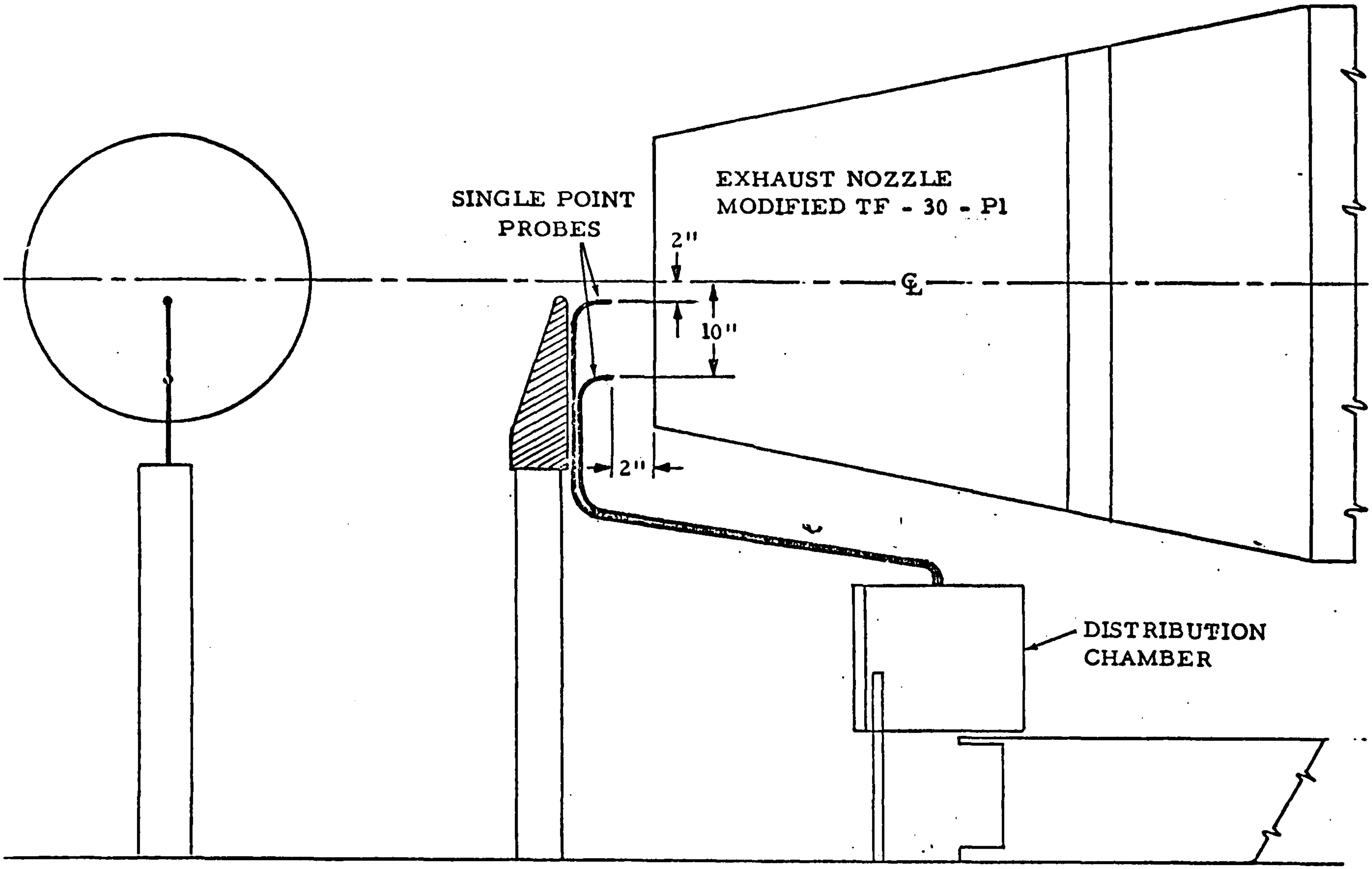


FIGURE 2. SAMPLING PROBE LOCATIONS

Fig. 3

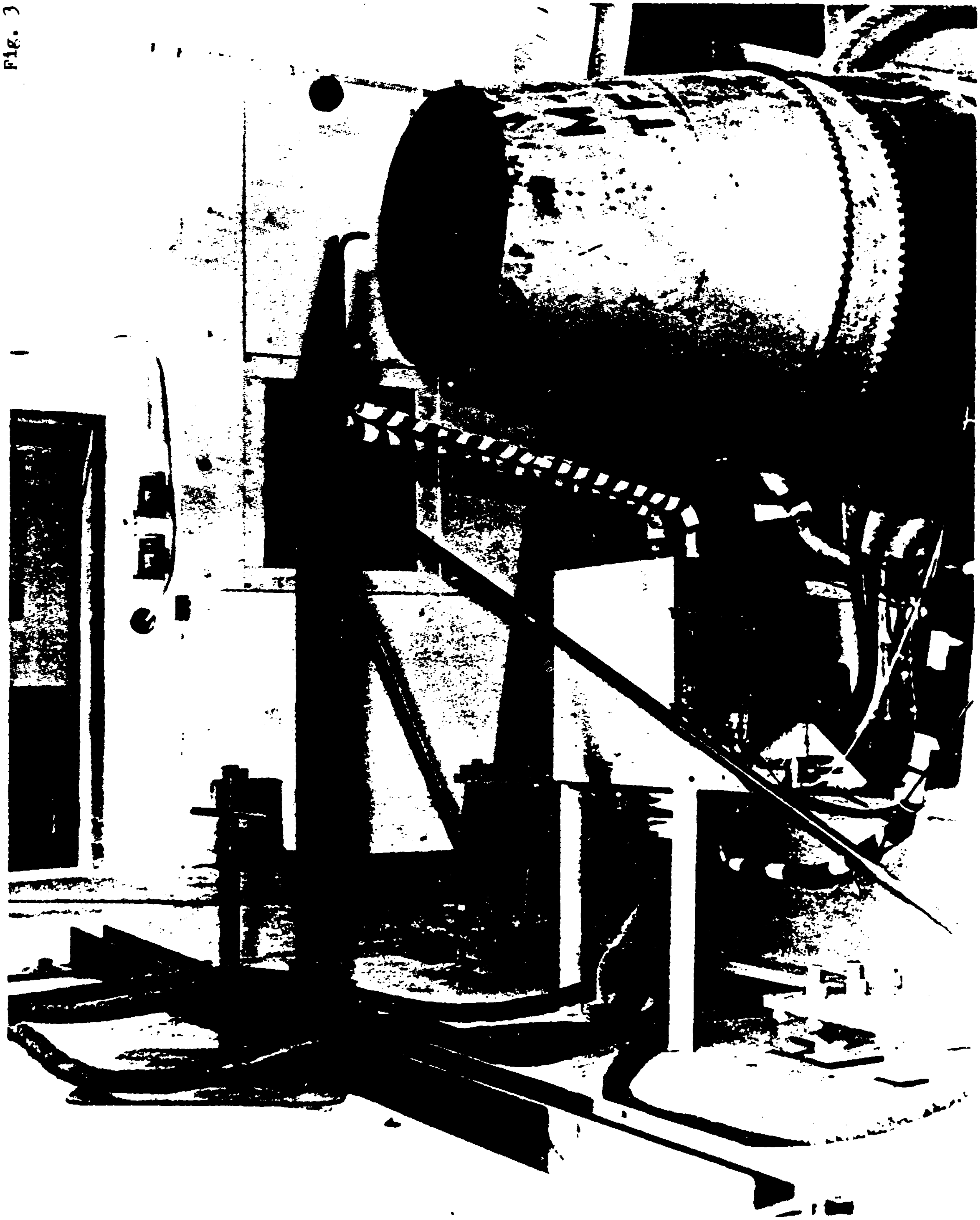


FIGURE 3. SAMPLING PROBE LOCATION PHOTOGRAPH

B. Instrumentation

The FAA provided three separate measurement systems used in the program. The first was a stationary, rack-mounted gas analysis system referred to as the "Console". The other two were trailer-mounted systems referred to as "Mobile Emissions Research Facilities" (MERF1 and MERF2) (see Figure 4). Pratt and Whitney had a truck mounted system, NGTE used a trailer-mounted system, both GE and NAPC had rack-mounted systems which were moved to Atlantic City.

Although the participants used gas analyzers made by different vendors, the operating principle was the same in all cases. The CO and CO_2 instruments were non-dispersive infrared analyzers. The total hydrocarbon analyzers were flame ionization detector (FID) units. The NO_x analyzers operated on the chemiluminescent principle. Thermal converters were used with the NO_x analyzers to allow both NO and NO_x modes of operation.

The smoke analyzers were all built and operated in accordance with SAE ARP 1179[4] except for the presence of the distribution chamber and used the stained filter paper method. The filter paper stains were then measured with an optical reflectometer.

Each participant used his own computer system and program for reducing the raw data. The final values for gas concentrations and SAE smoke number (SN) were then reported to the CRC Test Coordinator who compiled all the data.

C. Span Gases

Each participant provided his own zero and span gases for the calibration of his particular analyzers. In addition, a set of span gases was provided by the FAA to be used in the span gas bias tests. These gas cylinders were supplied and analyzed by Scott Environmental Technology.

The low concentration gases were:

CO	34.20 ppm
CO_2	1.49 %
THC	11.97 ppm C (as C_3H_8)
NO	9.36 ppm

The high concentration gases were:

CO	444.0 ppm
CO_2	2.96 %
THC	174.3 ppm C (as C_3H_8)
NO	107.0 ppm

Fig. 4

FIGURE 4. MOBILE EMISSIONS RESEARCH FACILITY

All gas concentrations listed in this report are given in ppm (by volume) or percent (by volume).

Gas mixtures were contained in cylinders corresponding high power engine operation and low power operation. Four different mixtures, or blends, were used. The four blends were: (1) high power blend of CO, CO_2, and THC; (2) low power blend of CO, CO_2, and THC; (3) high power concentration of NO; and (4) low power concentration of NO. The CO, CO_2, and THC blends had balance air; the NO blend was balance N_2. In addition, four identical cylinders of each blend were purchased so that identical concentration gases could be used throughout the program. All four participants were able to analyze the same gas simultaneously.

V. TEST PROCEDURE

During the planning process it was agreed that it was not practical to have all the participants at Atlantic City at the same time, but that four participants at a time was a manageable number. A testing schedule was established covering a period of five weeks. A staggered arrangement was used in which each of the four visiting participants was scheduled for two consecutive weeks. The scheduling arrangement along with the sampling port assignments are shown in Table III.

TABLE III

SAMPLING PORT ASSIGNMENTS BY PARTICIPANT

	Sampling Port Number	Participants 1	2	3	4
Week	Test Week Date				
1	10-24-78	3	2	4	1
2	10-31-78	3	5	4	1
3	11-7-78	3	5	6	1
4	11-14-78	3	7	6	1
5	3-14-79	3	7	2	1

The NAFEC Console (Participant 3) and MERF1 (Participant 1) were on test during all five weeks. MERF2 (Participant 2) was used during weeks 1 and 5 to fill out the schedule, and thus provide four participants for each of the five weeks.

A test sequence was established for a one-week period in which the engine was run at a number of power settings (Modes 1 through 6) to provide a range in emission concentrations. The same sequence was repeated for each of the five weeks. The order of power settings was changed within the different sequences to provide information on emission measurement hysteresis although not a major test objective and not analyzed in this report. The weekly test sequence is shown in Table IV.

TABLE IV

TEST SEQUENCE

Probe	High Concentration		Low Concentration		
Sequence	A	B	C	D	E
Measurements	Gaseous	Gaseous	Gaseous	Gaseous	Smoke
Engine Modes	1	1	1	1	1
	2	6*	2	6*	2
	3	5	3	5	3
	4	4	4	4	5*
	5	3	5	3	3
	6*	2	6*	2	2
	5	1	5	1	1
	4	2	4	2	5*
	3	3	3	3	3
	2	4	2	4	2
	1	5	1	5	1
		6*		6*	2
		1		1	
		2		2	

Where:

Mode	Nominal Power
1	Idle
2	High Idle
3	Approach
4	Cruise
5	Max Continuous
6	Take-off

* No emissions readings taken at these points.

To provide consistent measurements, the engine was allowed to stabilize before taking measurements. The stabilization times were 20 minutes for initial start to idle, 10 minutes for subsequent idle settings, and 5 minutes for all other engine mode settings. Emission measurements were not made at the take-off power setting (Mode 6) due to engine run time limitations.

The original test sequence plan called for smoke readings at high power setting. During the first week of testing it was discovered that this gave very high smoke numbers which are no longer encountered in current low smoke technology engines. Consequently, the smoke sequence was revised as shown in Table IV, beginning with the second week. Smoke readings were then taken only at idle, high idle, and approach modes with the low concentration probe.

The weekly test sequence also included a pretest span gas bias check which was run just prior to the engine emission test, and a post test span gas bias check which was run just after the engine gaseous emission test and before the smoke test. During the span gas bias test all eight of the special span gas concentrations were checked, and each participant took four replicate readings of each gas.

VI. TEST DATA

The test data used in this analysis is reproduced in the appendices as follows:

- Appendix B - Calibration Gas Measurement Summary

  This appendix contains all the emissions span gas results for the four gases: CO, CO_2, THC, and NO_x. The levels reported are the average of four readings for each participant and are accompanied by an estimate of each participant's standard deviation, 1S. These tables also list each test day's average across participants for each span gas, X, along with an estimate of daily participant-to-participant variability.

- Appendix C - Gaseous Exhaust Measurement Data

  This appendix contains all the emissions data analyzed for this report. It is the engineering unit data from each participant's instruments. It is the intent of this analysis to utilize, in the final results, each participant's test data without correcting them to the calibration gas standards used at the test site to evaluate each participant's calibration gases. These results would reflect what would normally result from inter-

facility comparisons where no standard gas is exchanged for corrections. The exception was to allow corrections to NGTE data due to their analysis of their calibration gases[6] which had to be done after the test; every other participant had time to complete that analysis before the test.

- Appendix D - Smoke Data

  This appendix contains all the smoke data available for this analysis. Only the data from the low concentration probe at power levels of approach and below were analyzed to try to screen out some of the very high smoke numbers obtained from the engine, but not typical of current low smoke technology. Even with that screening, however, smoke results are of doubtful current value as the lowest smoke number in all the data is greater than 20.

A complete, detailed tabulation of all the test data from this program is on file in the CRC compendium cited as Reference 1.

VII. DATA ANALYSIS

This section will outline the analysis performed to determine participant-to-participant variability on clean span gases, participant-to-participant variability on exhaust emissions, individual participant precision errors, and the bias introduced by span gases along with the results of an attempt to remove that bias. The smoke data analysis is also discussed. Detailed definitions of precision and bias may be found in the ASME Test Code Supplement[7].

A. Participant-to-Participant Variability on Clean Span Gases

Each participant measured the gas concentration levels of gas mixtures intended to simulate low- and high-power engine emissions. The span gas vendor analysis results were as shown in Section IV-C.

Each participant analyzed each gas four times on each of two days during each week they were present at the test site. The average values for each of those sets of four are shown in Appendix B, along with each participant's 1S variability.

Setting each span gas measurement as 'X', we have:

X_{ijk} = individual gas measurement

where: i = 1 to 4, the number of repeat readings on one gas

j = 1 to 10, the number of the test day, 2 days each of 5 weeks

k = 1 to 4, the number of participants present during any one day

We, therefore, have an array of averages and standard deviations, given in Appendix B, of:

$$
\begin{array}{ccc}
\overline{X}_{jk} & \cdots\cdots & \overline{X}_{j,4} \\
S_{jk} & \cdots\cdots & S_{j,4} \\
\vdots & & \vdots \\
\overline{X}_{10,k} & \cdots & \overline{X}_{10,4} \\
S_{10,k} & \cdots & S_{10,4}
\end{array}
$$

where: $\overline{X}_{jk} = \sum_{i=1}^{N_{jk}} \frac{X_{ijk}}{N_{jk}}$; the average span gas reading of participant k on day j.

$S_{jk} = \left\{ \frac{\sum_{i=1}^{N_{jk}} (X_{ijk} - \overline{X}_{jk})^2}{N_{jk} - 1} \right\}^{1/2}$; the span gas reading standard deviation of participant k on day j.

N_{jk} = 4 (usually), the number of repeat span gas readings by each participant.

The $\overline{X}_{jk}$ and S_{jk} are listed for each participant and span gas in Appendix B and are listed under the general heading, Avg. $\pm$1S.

To determine the participant-to-participant variability, a new array is created:

$$
\begin{array}{cc}
\overline{X}_j & 2S_j \\
\cdot & \cdot \\
\cdot & \cdot \\
\cdot & \cdot \\
\overline{X}_{10} & 2S_{10}
\end{array}
$$

where: $\overline{X}_j = \sum_{k=1}^{N_j} \overline{X}_{jk/Nj}$; the average span gas reading of all participants on day j.

$$2S_j = 2\left\{\frac{\sum_{k=1}^{N_j} (\overline{X}_{jk} - \overline{X}_j)^2}{N_j - 1}\right\}^{1/2}$$; the standard deviation of span gas readings by all participants on day j.

N_j = 4 (usually), the number of participants on day j.

From the above array, we calculate:

$$\overline{\overline{X}} = \sum_{j=1}^{L} (\overline{X}_j)\ (N_j) / \sum_{j=1}^{L} N_j$$; the grand average span gas reading of all participants on all days.

$$2S_p = \left\{\frac{\sum_{j=1}^{L} (2S_j)^2\ (N_j-1)}{\sum_{j=1}^{L} (N_j-1)}\right\}^{1/2}$$; the pooled standard deviation of span gas readings for all participants across days.

L = 10 for 5 weeks of data and 8 for 4 weeks of data.

The $\overline{X}_j$ values are in the third column from the right in Appendix B and are listed under the heading, $\overline{X}$.

The $2S_j$ values are shown in the extreme right columns of the tables in Appendix B and are listed under the heading, $2S_x$.

The $2S_p$ values are the participant-to-participant variability and are presented for each constituent and level, X, along with their degrees of freedom (d.f.) in Tables V-A and V-B. Table V-A is for all participants, 5 weeks data. Table V-B is for only 4 weeks data and does not include Participant 7. Table V-B presents the final results of the span gas comparisons intended to yield participant-to-participant variability on clean span gases.

Note that no attempt has been made to remove from Tables V-A or V-B the contribution due to each participant's precision on span gases, S_{jk}. Removing it would have negligible impact on the presented results. Note too that although some Participant 7 values shown in Tables B-I through B-IV were obvious outliers, they were not omitted from the calculation results shown in Table V-A so the effect of including Participant 7 could more clearly be shown.

TABLE V-A

PARTICIPANT-TO-PARTICIPANT CALIBRATION VARIABILITY (AVG. ± 2S)

(All Participants / 5 Weeks' Data)

		Constituent			
		CO, ppm	CO_2, %	THC, ppmC	NO_x, ppm
Calibration	Low	34.2	1.49	11.97	9.36
Gas Concen.	High	444.0	2.96	174.3	107.0
Variability	- Low	35.7± 9.5	1.49±0.074	16.1±18.3	8.97±2.3
(Avg. ±2S)	- High	448.2±25.4	2.96±0.158	171.0±68.9	106.6±18.0
±2S/Avg.-%; d.f.					
Low		±26.6;26	±5.0;29	±113.7;28	±25.6;28
High		± 5.7;28	±5.3;29	± 40.3;29	±16.9;29

Note: d.f. = Degrees of Freedom

TABLE V-B

PARTICIPANT-TO-PARTICIPANT CALIBRATION VARIABILITY (AVG. ± 2S)

(All Participants Except Number 7 / 4 Weeks' Data)

		Constituent			
		CO, ppm	CO_2, %	THC, ppmC	NO_x, ppm
Calibration Gas Concen.	Low	34.2	1.49	11.97	9.36
	High	444.0	2.96	174.3	107.0
Variability (Avg. ±2S)	- Low	34.1± 3.6	1.48±0.057	14.7±11.2	9.22±0.78
	- High	444.6±16.9	2.94±0.091	178.8±16.2	109.0±6.1
±2S/Avg.-%; d.f.					
Low		±10.6;19	±3.9;21	±76.2;22	±8.5;21
High		± 3.8;22	±3.1;21	± 9.1;22	±5.6;22

Note: d.f. = Degrees of Freedom

B. Participant-to-Participant Variability on Exhaust Gases

Each participant measured exhaust gases simultaneously (alternating between a high and low concentration probe) when the engine stabilized at each of five power levels (modes). All the test data secured are shown in Appendix C, Gaseous Exhaust Measurement Data. To proceed with this analysis, probe/mode combinations were chosen for each gas at each of two concentration levels which approximated the levels of the span gases. There were three to five data points per probe/mode combination for each of the four participants.

For those data chosen, the participant-to-participant variability and the individual participant precision were determined by Grubbs' method[5]. This was the same method used by Wedlock[6] in his partial analysis of the data. This analysis method yields estimates of:

a. Individual participant precision;

b. Participant-to-participant variability which includes the effect of "a" above;

c. Engine variability, the repeatability of setting the engine conditions.

Participant-to-participant variability was determined by the Grubbs' method as follows:

Let Y_{ijk} = an exhaust gas measurement during a given week

where: i = 1 to 4, the number of the participant sampling a data point

j = 1 to 4, the number of the probe/mode combination approximating the calibration gas levels used

k = 1 to 5, the number of the data or sample point matching each probe/mode combination, j

The variability between each participant on a data point is then computed as:

$$2S_{pjk} = 2\left[\frac{\sum_{i=1}^{I}(Y_{ijk} - \overline{Y}_{jk})^2}{I-1}\right]^{1/2}$$

where: $\overline{Y}_{jk} = \sum_{i=1}^{I} Y_{ijk}/I$ and

I = 4, usually, the number of participants sampling a data point

Then the $2S_{pjk}$ values are pooled across the points sampled during a given week at the probe/mode combination chosen:

$$2S_{p(pool)j} = \left[\frac{\sum_{k=1}^{K}(2S_{pjk})^2}{K}\right]^{1/2}$$

where: K = 3 to 5, the number of sample points matching the jth probe/mode combination chosen

The Grubbs' calculation yields the individual participant precision, S_i, for a given probe/mode combination. The details of this calculation are given in Reference 5 and will not be repeated here. The S_i values are pooled using the following relation:

$$2\hat{S} = 2\left[\left(\sum_{i=1}^{I} S_i^2/K_i\right)/I\right]^{1/2}$$

where: S_i = Individual participant precision for each participant, i

K_i = 3 to 5, the number of test points used to calculate S_i

I = the number of participants (usually 4)

Participant-to-participant precision and bias are bound up in $2S_{p(pool)j}$ and are not separable. The effect of individual participant precision on participant-to-participant variability is removed by the following calculation:

$$2S_{pp} = \left[(2S_{p(pool)j})^2 - (2\hat{S})^2\right]^{1/2}$$

where: $2S_{pp}$ = Participant-to-participant variability

The individual participant precision is usually small relative to the participant-to-participant variability. ($2S_{pp}$) is the participant-to-participant variability for a given gas, for a given probe/mode combination, and for one week only. These values are pooled over all 4 or 5 weeks, as required, to give:

$$2S_{pp*} = \left\{\frac{\sum_{m-1}^{M} [(2S_{pp})^2(df_m)]}{\sum_{m=1}^{M}(df_m)}\right\}^{1/2}$$

where: df_m = number of degrees of freedom for the mth week

M = 4 or 5, the number of weeks included

($2S_{pp*}$) is the overall participant-to-participant variability for one given probe/mode combination.

These values are pooled across the probe/mode combinations chosen for the particular gas and emission level (see Table VII) to yield:

$$2S_{pp**} = \left[\frac{\sum_{j=1}^{J} (2S_{pp*})^2}{J} \right]^{1/2}$$

where: J = 2 to 4, the number of probe/mode combinations used.

The detailed calculations performed using Grubbs' method[5] are on file in the CRC office.

The participant-to-participant variability $2S_{pp**}$ is presented in Tables VI-A and VI-B, in which each $2S_{pp**}$ is shown along with the average levels. (Degrees of freedom were always 30 or above, so $2S_{pp**}$ is appropriate). Table VI-A is for all seven participants and five weeks data. Table VI-B is for six participants and four weeks data. Participant Number 7 was excluded as being much too erratic.

Table VI-B represents the final results of the study; it describes the expected variability between laboratories testing the same engine at the same time.

The probe/mode combinations used in calculating Tables VI-A and VI-B are shown in Table VII.

TABLE VI-A

PARTICIPANT-TO-PARTICIPANT TEST VARIABILITY (AVG. ±2S)

(All Participants / 5 Weeks' Data)

	Constituent			
	CO, ppm	CO_2, %	THC, ppmC	NO_x, ppm
Concentration* (Avg. ±2S)				
Low	35.4±14.4	1.67±0.15	17.7± 8.2	13.4±4.7
High	505.9±20.4	2.66±0.27	204.0±110.2	81.1±7.6
±2S/Avg. - %				
Low	±40.6	± 9.2	±46.6	±35.2
High	± 4.0	±10.0	±54.0	± 9.4

* Concentrations chosen to approximate calibration gas levels. All degrees of freedom over 30.

TABLE VI-B

PARTICIPANT-TO-PARTICIPANT TEST VARIABILITY (AVG. ±2S)

(All Participants Except Number 7 / 4 Weeks' Data)

	Constituent			
	CO, ppm	CO_2, %	THC, ppmC	NO_x, ppm
Concentration* (Avg. ±2S)				
Low	32.4± 8.1	1.68±0.11	17.9± 2.9	14.1±1.7
High	496.6±18.6	2.66±0.14	210.6±15.8	82.0±5.0
±2S/Avg. - %				
Low	±24.9	±6.5	±16.0	±11.9
High	± 3.7	±5.4	± 7.5	± 6.1

* Concentrations chosen to approximate calibration gas levels. All degrees of freedom over 30.

TABLE VII

PROBE/MODE * COMBINATIONS OF THE DATA INCLUDED IN TABLES VI-A, VI-B, AND X

	Constituent			
Concentration	CO	CO_2	THC	NO_x
Low	1/4,1/5, 2/5	1/4,1/5, 2/1,2/2	1/3,2/3	1/2,1/3, 2/1,2/2
High	2/1,2/2	2/4,2/5	2/1,2/2	2/4,2/5

* Note:

Probe Code	Mode Code
1 = Low sample concentration	1 = Idle
	2 = High Idle
	3 = Approach
2 = High sample concentration	4 = Cruise
	5 = Max. Continuous

C. Individual Participant Precision Errors

The Grubbs' analysis[5], as mentioned above, yields individual participant precision errors. Those precision errors, appropriately pooled over the same probe/mode data points given in Table VII, are shown in Table VIII along with their average values. Table VIII and all subsequent tables include four weeks' data and do not include Participant Number 7.

The Fortran program utilized to perform the Grubbs' analysis[5] was obtained from NGTE and run at General Electric, Cincinnati. A copy of the Fortran listing is at the CRC office for reference.

TABLE VIII

INDIVIDUAL PARTICIPANT TEST DATA PRECISION

(Average Concentration ±2S), Low and High
(2S/Average in Percent), Low and High

	Constituent			
Participant	CO, ppm	CO_2, %	THC, ppmC	NO_x, ppm
1 - Low	32.5±1.2	1.68±0.05	18.3±2.1	14.1±0.8
High	497.1±5.4	2.66±0.07	213.5±8.3	82.0±2.7
Low %	±3.7	±2.8	±11.3	±5.7
High %	±1.1	±2.7	± 3.9	±3.3
2 - Low	30.1± 2.2	1.69±0.02	17.0±3.5	13.9±3.0
High	490.0±18.1	2.64±0.03	203.0±9.9	83.2±7.3
Low %	±7.4	±1.3	±20.6	±21.5
High %	±3.7	±1.2	± 4.9	± 8.8
3 - Low	32.5±1.3	1.68±0.14	18.0±2.2	14.1±1.2
High	497.1±3.9	2.66±0.14	210.9±5.4	82.0±1.4
Low %	±3.9	±8.4	±12.2	±8.3
High %	±0.8	±5.4	± 2.5	±1.7
4 - Low	30.5±1.9	1.69±0.06	17.0±2.8	14.2±0.8
High	492.3±4.9	2.65±0.06	198.8±7.9	83.1±4.3
Low %	±6.1	±3.6	±16.4	±5.7
High %	±1.0	±2.4	± 4.0	±5.2
5 - Low	32.7±4.4	1.67±0.05	17.0±1.0	14.1±1.4
High	496.5±5.4	2.66±0.11	208.8±3.1	81.1±2.8
Low %	±13.4	±3.0	±5.7	±9.7
High %	± 1.1	±4.2	±1.5	±3.4
6 - Low	34.5±1.8	1.67±0.10	19.0± 3.8	14.0±0.9
- High	501.9±6.7	2.67±0.15	222.9±14.6	80.9±2.6
Low %	±5.3	±6.1	±20.2	±6.1
High %	±1.3	±5.6	± 6.6	±3.2

* All degrees of freedom over 30.

D. Bias Introduced by Each Participant's Span Gases

From the data in Appendix B, an estimate of the contribution of span gas bias to participant-to-participant variability may be calculated. This is done by comparing each participant's average value for the span gas with that obtained on that day by a referee system, the FAA Console. These calibration (or span) gas correction factors are given in Table IX where the Console average is divided by the participant's average. The gas concentrations are the analysis levels provided by Scott.

TABLE IX

CALIBRATION GAS CORRECTION FACTORS

CONSOLE DATA/PARTICIPANTS DATA

(All Participants Except Number 7 / 4 Weeks' Data)

Participant :	1	2	4	5	6
Gas (~conc.)					
CO (34.2 ppm)	0.975	0.9881	0.9549	0.9374	0.8743
CO (444.0 ppm)	1.023	0.9934	0.9963	0.9879	0.9739
CO_2 (1.49%)	1.016	1.000	1.000	0.9933	0.9850
CO_2 (2.96%)	0.997	0.9915	1.006	1.020	1.012
THC (11.97 ppmc)	0.522	0.5681	0.8773	0.8798	0.9991
THC (174.3 ppmc)	0.912	0.9233	0.9731	0.9952	0.9733
NO_x (9.36 ppm)	0.990	0.9876	0.9736	1.009	0.9204
NO_x (107.0 ppm)	0.978	1.033	0.9989	0.9592	0.9657

The original data given in Appendix C were multiplied by the appropriate factors from Table IX to give the "calibration gas corrected" data. These data were then used to compute Table X. The "calibration gas corrected" data show no significant improvement over the "uncorrected" data in Table VI-B.

TABLE X

PARTICIPANT-TO-PARTICIPANT TEST VARIABILITY (AVG. ± 2S)

CALIBRATION GAS CORRECTED

(All Participants Except Number 7 / 4 Weeks' Data)

	Constituent			
	CO, ppm	CO_2, %	THC, ppmC	NO_x, ppm
Concentration* (Avg. ±2S)				
Low	31.0± 5.4	1.68±0.10	14.7± 9.0	13.8±1.8
High	496.5±12.4	2.67±0.17	203.4±20.5	80.8±3.6
±2S/Avg. - %				
Low	±17.5	±5.9	±60.9	±13.0
High	± 2.5	±6.4	±10.1	± 4.5

* Concentration chosen to approximate calibration gas levels. All degrees of freedom are over 30.

Table VI-B is the final result of this analysis. It does not include the effect of individual precision errors. It does however include any span gas caused differences which would be difficult to evaluate when comparing test results from separate facilities.

E. Smoke Analysis

The smoke data utilized is presented in Appendix D. The results of the brief regression analysis of the smoke data are presented in Table XI. These smoke data were insufficient to provide adequate determination of present day participant-to-participant variability.

TABLE XI

REGRESSION ANALYSIS OF SMOKE MEASUREMENTS

(All Data Referenced to FAA Console)

Participant	No. of Data Points	Slope	Intercept SN	Correlation Coefficient	Standard Error of Estimate SN	SN at Refer. of 30
1	40	1.098	1.17	0.958	4.32	34.1
4	9	1.108	-1.83	0.970	3.27	31.4
5	16	1.166	-2.64	0.983	2.76	32.3
6	20	1.045	2.46	0.987	2.17	33.8
7	10	1.129	8.89	0.986	2.40	42.8

F. Outlier Rejection

In all the above analysis, the Grubbs outlier rejection method of Reference 8 was employed. It was used as the basis for rejecting individual points and for rejecting one participant.

VIII. RESULTS AND DISCUSSION

It is the intent of this section to present and discuss the analysis results from two perspectives: the meeting of test objectives, and other comparisons of interest.

A. Meeting of Test Objectives

- Objective 1 - "Establish a Cross-Correlation"

  This objective was met with completion of the testing at NAFEC.

- Objective 2 - "Determine Typical Variability Between Testing Groups"

  This objective is met by the presentation of Table VI-B and Table XI. Table VI-B provides estimates of the variability that can be encountered between testing groups measuring gaseous emissions on the same turbine engine. The 2S variability shown does not include the effect of individual participant precision but does include the effect of difference in each participant's calibration gases. In applying the data in Table VI-B to future comparisons, the effect of each participant's precision needs to be worked into the analysis. This usually can be done after evaluating the precision errors during test. The effect of calibration gas differences was left in the results in Table VI-B because future testing would likely not provide for easy comparisons of calibration gases. The calibration gas differences are, therefore, taken as typical for future tests as well.

  It should be noted that Table VI-B does not include Participant Number 7 or Week 5 data. A comparison of Tables VI-A (which includes Participant 7) and VI-B illustrates clearly why the decision to eliminate Participant Number 7 was made. As a participant, Number 7 was an outlier; it was therefore eliminated from all further analysis.

Note also that while the EPA has a ±2% specification on calibration gases, analyzer drift, etc., there should be the awareness that participant-to-participant variability is an accumulation of those errors plus errors from other sources. The result can be variability greatly in excess of ±2%, as the data in Table VI-B show.

In addition, the results in Table VI-B were obtained under carefully controlled conditions such as existed at NAFEC for this comparison. Less controlled conditions would probably yield increased variability.

Table XI presents the results of the regression analysis of smoke measurements. A simple regression analysis was used for smoke since there were not enough data to perform the Grubbs' analysis[5] used for the gaseous emissions. While a direct comparison is not possible, the low correlation coefficients and high standard errors of estimate for smoke show that the variability for smoke is considerably greater than that for the gaseous emissions. This points out the fact that of the various measurements made under this program, smoke measurement is the area most in need of improvement.

It should be noted that in this report, the smoke measurements were in the SN range from 20 to 80. This range is too high to be applicable to current engine technology where smoke numbers are usually 20 or lower.

- Objective 3 - "Estimate Participant Precision Errors and Evaluate Their Effect on Observed Variability"

This objective was met by the presentation of Appendix A and Table VIII. Appendix A presents individual participant precision (1S) on clean span gases. By inspection, it is shown that these 1S values have a negligible effect on span gas comparisons. Table VIII presents the individual participant precision errors for each participant as revealed by measuring test gases. These data are much more representative of errors that effect test comparisons than are the data in Appendix A. The effect of the precision errors in Table VIII is not included in the results in Table VI-B; however, upon inspection, they are seen to have measurable but small effects. The major source of the variability in Table VI-B was participant-to-participant variability, not individual participant precision.

- Objective 4 - "To Evaluate the Bias Introduced by Span Gases"

This objective was met with the presentation of Table IX, "Calibration Gas Correction Factors." These factors were determined by choosing Participant 3 (FAA Console) as a referee present for all testing, and comparing all participants' calibrations to that. The average of all the correction factors (eliminating the two THC outliers of 0.522 and 0.5681) is 0.9765, and the 2S is $\pm$0.0798 ($\pm$8.2%). The scatter (2S) in these correction factors should be representative of participant-to-participant calibration gas scatter (plus a negligible instrument precision contribution). If all the participant span gases were within the recommended accuracy of $\pm$2%, the correction factor 2S would be $\pm 2 \times \sqrt{2}$ or $\pm$2.8% (scatter of differences, or ratios, between two participants). Since the observed scatter is $\pm$8.2%, there is the suggestion that the individual span gases of the participants are only good to $\pm 8.2 \div \sqrt{2}$ or $\pm$5.8%. This is more than eight times the permitted variability of $\pm$2% ($5.8^2 \div 2^2$). Apparently, even on clean span gases, participants can't agree within EPA guidelines.

B. Other Comparisons of Interest

Table X presents the participant-to-participant variability determined after correcting the data sets by the calibration gas factors of Table IX. A comparison of Table X with VI-B shows that the calibration gas corrections had little effect on participant-to-participant variability. The variability is due to some other major system-to-system error source or sources which have not been identified.

Tables XII-A and XII-B present the pooled participant test precision as a percent of level. Table XII-A is for all participants, five weeks' data; and Table XII-B all but Participant 7, four weeks' data. The data in Tables XII-A and XII-B are shown in bargraphs in Figures 5A and 5B. Note that with the elimination of Participant 7, the data becomes well behaved. It shows that participant test precision as a percent of level decreases with increasing concentration. The results shown in Figure 5 also contributed to the rationale for eliminating Participant 7 as an outlier.

TABLE XII-A

BARGRAPH DATA FOR POOLED PARTICIPANT TEST PRECISION

(All Participants / 5 Weeks)

Gas	CO									
Probe/Mode	1/5	1/4	2/5	2/4	1/3	1/1	1/2	2/3	2/2	2/1
Concentration (ppm CO)	27.5	35.0	43.6	57.9	84.0	147.2	147.3	178.2	485.9	525.9
±2S/Avg. %	50.0	43.9	32.0	40.9	23.1	10.6	11.1	12.3	4.1	4.0

Gas	CO_2									
Probe/Mode	1/1	1/2	1/3	1/4	1/5	2/1	2/2	2/3	2/4	2/5
Concentration (% CO_2)	0.58	0.68	0.98	1.47	1.69	1.73	1.79	1.98	2.53	2.79
±2S/Avg. %	12.5	12.0	9.7	7.2	6.2	10.6	11.0	10.6	10.8	9.3

Gas	THC									
Probe/Mode	2/5	1/5	2/4	1/4	1/3	2/3	1/2	1/1	2/2	2/1
Concentration (ppmC THC)	3.6	4.0	4.1	4.1	11.7	23.6	40.8	52.3	185.8	222.1
±2S/Avg. %	109.8	56.8	98.5	54.3	48.7	42.9	58.8	57.7	52.7	54.6

Gas	NO_x									
Probe/Mode	1/1	1/2	1/3	2/1	2/2	2/3	1/4	1/5	2/4	2/5
Concentration (ppm NO_x)	4.8	6.4	14.9	15.0	17.2	31.8	37.8	52.5	70.1	92.0
±2S/Avg. %	33.8	32.3	22.4	39.4	36.0	25.7	31.7	23.7	10.0	8.9

TABLE XII-B

BARGRAPH DATA FOR POOLED PARTICIPANT TEST PRECISION

(All Participants Except Number 7 / 4 Weeks)

Gas	CO									
Probe/Mode	1/5	1/4	2/5	2/4	1/3	1/2	1/1	2/3	2/2	2/1
Concentration (ppm CO)	24.8	31.9	40.4	53.1	80.0	143.3	144.2	171.7	476.2	516.9
±2S/Avg. %	30.4	24.8	21.6	17.0	10.2	10.0	9.3	8.2	4.0	3.4

Gas	CO_2									
Probe/Mode	1/1	1/2	1/3	1/4	1/5	2/1	2/2	2/3	2/4	2/5
Concentration (% CO_2)	0.58	0.68	0.98	1.48	1.69	1.74	1.80	1.99	2.54	2.78
±2S/Avg. %	11.4	11.8	10.0	7.1	5.9	5.9	6.9	5.6	5.5	5.4

Gas	THC									
Probe/Mode	2/5	2/4	1/5	1/4	1/3	2/3	1/2	1/1	2/2	2/1
Concentration (ppmC THC)	3.3	3.7	4.1	4.2	11.7	24.0	42.0	53.8	192.4	228.7
±2S/Avg. %	77.3	73.3	51.4	50.3	17.2	14.6	10.3	9.3	7.0	7.8

Gas	NO_x									
Probe/Mode	1/1	1/2	1/3	2/1	2/2	2/3	1/4	1/5	2/4	2/5
Concentration (ppm NO_x)	4.9	6.5	15.5	16.0	18.3	33.1	39.7	54.5	71.1	92.8
±2S/Avg. %	31.2	27.3	13.7	8.3	7.5	7.2	6.7	6.6	6.0	6.1

IX. CONCLUSIONS

With few exceptions, it has been intended to limit the analysis to the major objective of this cross-correlation program; the conclusions are therefore similarly specific.

1. An emission measurement cross-correlation has been established between testing laboratories, experienced in gas turbine emission measurements, measuring the emissions of a single test engine.

2. The variability between testing laboratories is a function of emission gas and level. The variability is well in excess of $\pm 2\%$ for each participant with the one exception of CO_2 at high power.

3. Short-term instrument precision errors have a negligible effect on span gas comparisons.

4. Individual participant test precision errors are not a major factor in participant-to-participant test variability.

5. Individual participant test precision error as a percent of level is an inverse function of gas concentration.

6. Span gas bias errors from one participant to another are three times those recommended as acceptable to the EPA. Even on clean span gases, the EPA variability guideline of $\pm 2\%$ cannot be met.

7. Smoke numbers obtained in this analysis were too high as compared to current technology, low smoke engines, and were of insufficient quantity for meaningful conclusions. However, the average variability was much in excess of the expected SAE/ARP 1179 precision of ± 3 SN.

X. RECOMMENDATIONS AND FUTURE EFFORT

The results of this test program have indicated that the variability of emissions measurements from participant-to-participant are considerably higher than desired objectives. The question then arises as to what are the major causes of the variations. The following recommendations are directed toward a resolution of some of these questions.

1. The regulatory authorities should consider setting more realistic variability guidelines in light of the results of this test program.

2. An effort should be made to establish more detailed criteria for the operation of the emissions equipment to improve the measurement repeatability. There are many factors, such as ambient temperature conditions, sample line temperature and conditioning, ambient CO_2 level, to name a few, which can influence the analyzer outputs. These should be studied and better controlled whenever possible.

3. There are likely sufficient data available from the test program described in this report to permit a study of the hysteresis effects resulting from engine power level variation. These data should be statistically analyzed to determine whether or not hysteresis causes a significant error in the test results. Hysteresis will not effect results of comparisons in this report, since all participants made their measurements at the same time. It may, however, effect measurement of absolute engine emission levels.

4. The smoke measurement technique needs improvement. It may be necessary to replace the filter stain method with an entirely new method, such as an optical method, in order to accomplish a significant improvement in measurement accuracy.

5. Instrument manufacturers should be encouraged to improve the accuracy of their instruments, particularly at low levels. The total hydrocarbon analyzer, especially, needs improvement in this area.

6. To minimize the errors due to calibration gases, these gases should be periodically checked against reference standards which are traceable to the National Bureau of Standards.

7. Calibration gas "round-robin" programs should be continued in the future to monitor the progress which is being made in the improvement of calibration gas accuracy.

8. The data from Phase II of this program still need to be analyzed in order to increase the data base used in arriving at the program conclusions.

FIGURE 5A

POOLED PARTICIPANT TEST PRECISICN (2S/AVERAGE)

(All Participants/5 Weeks)

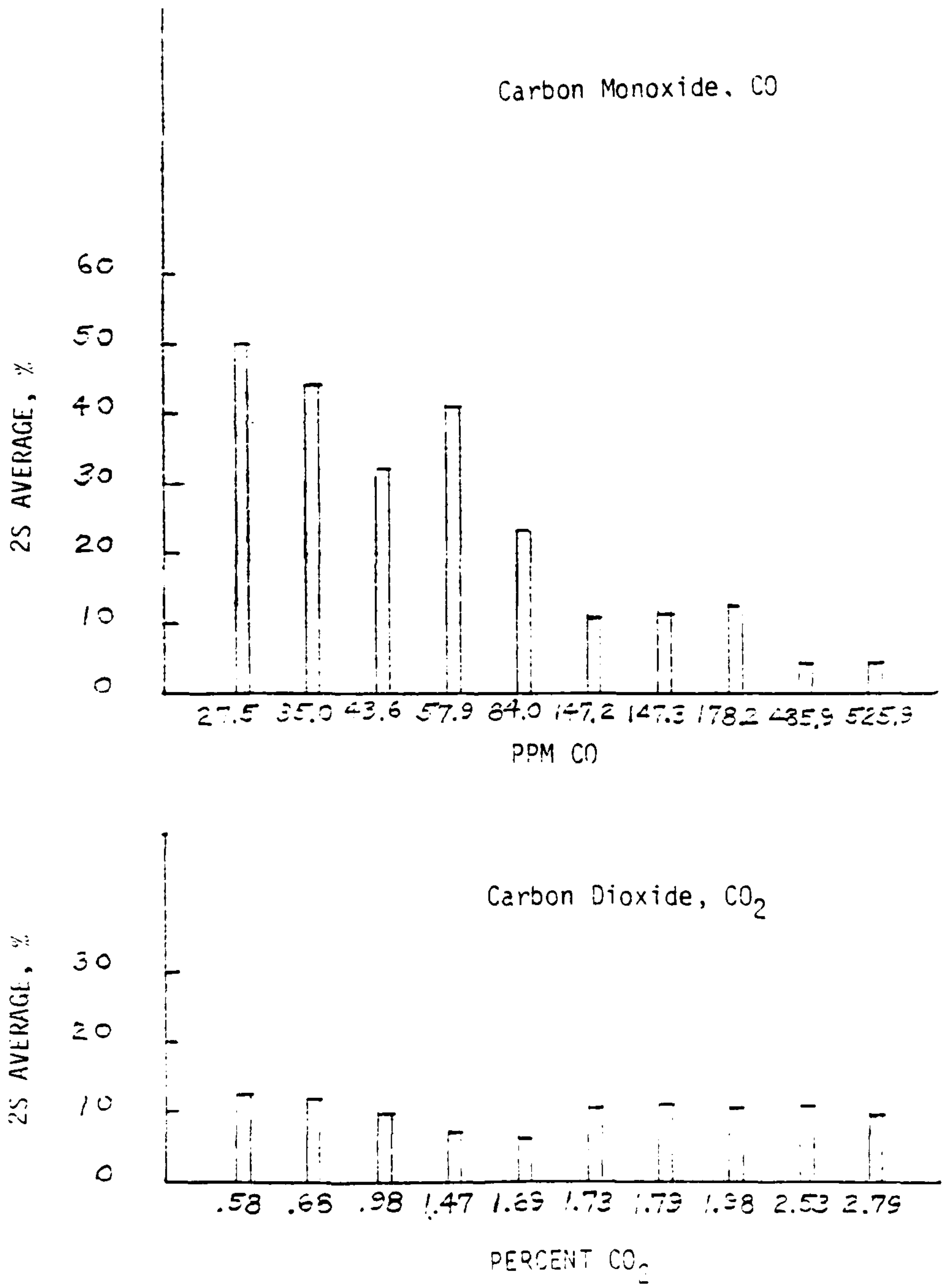
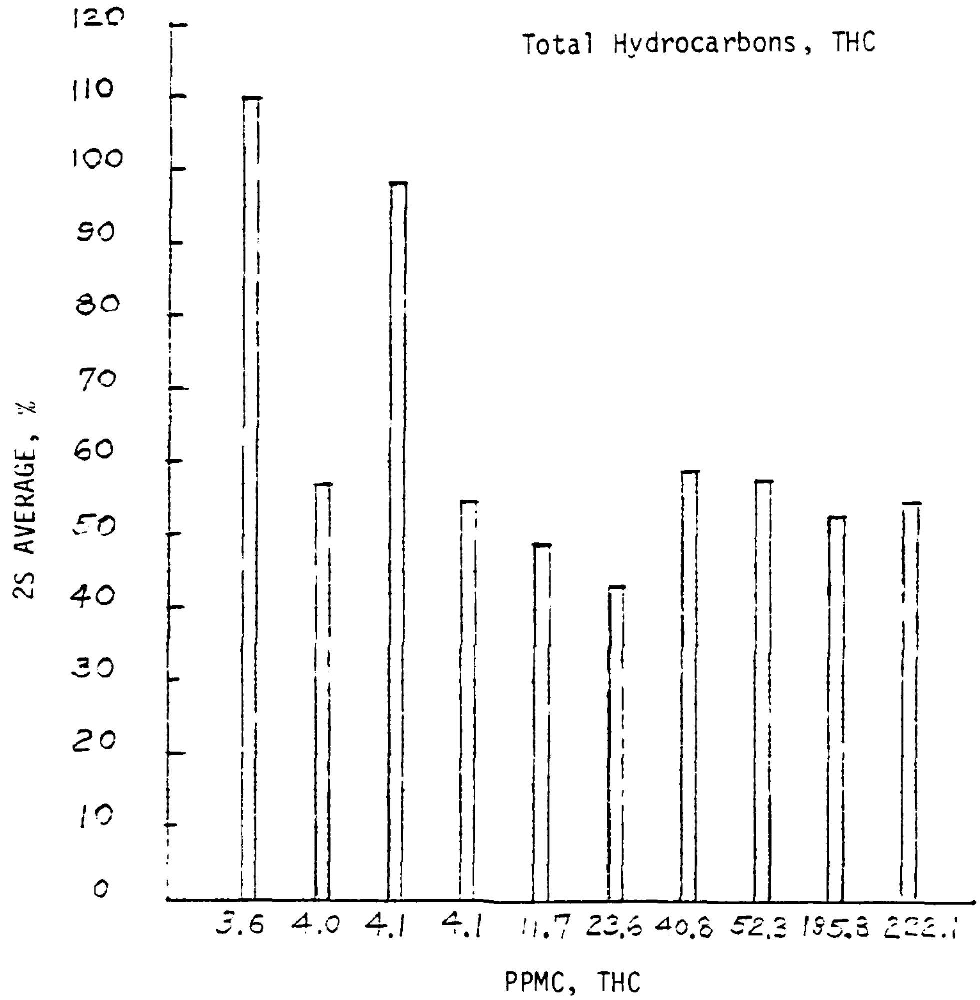


FIGURE 5A - (CONTINUED)



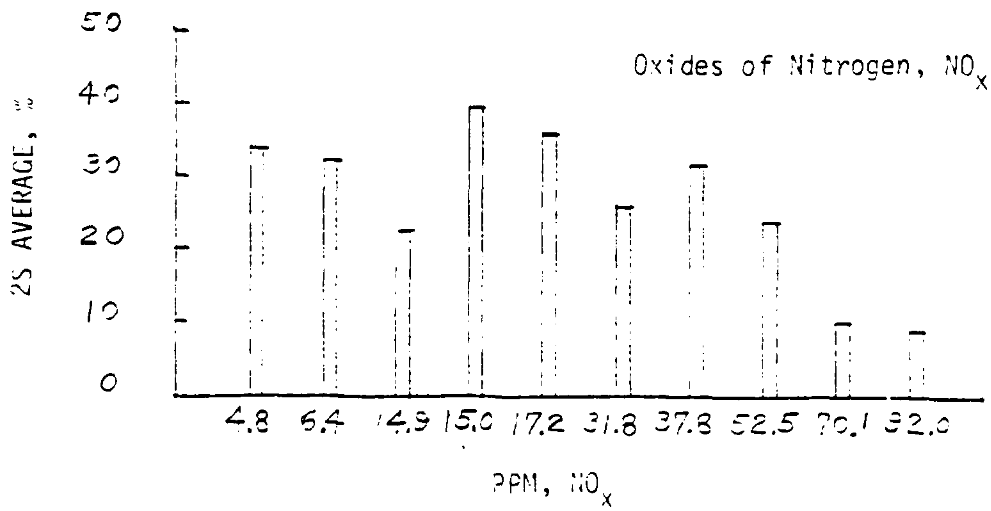
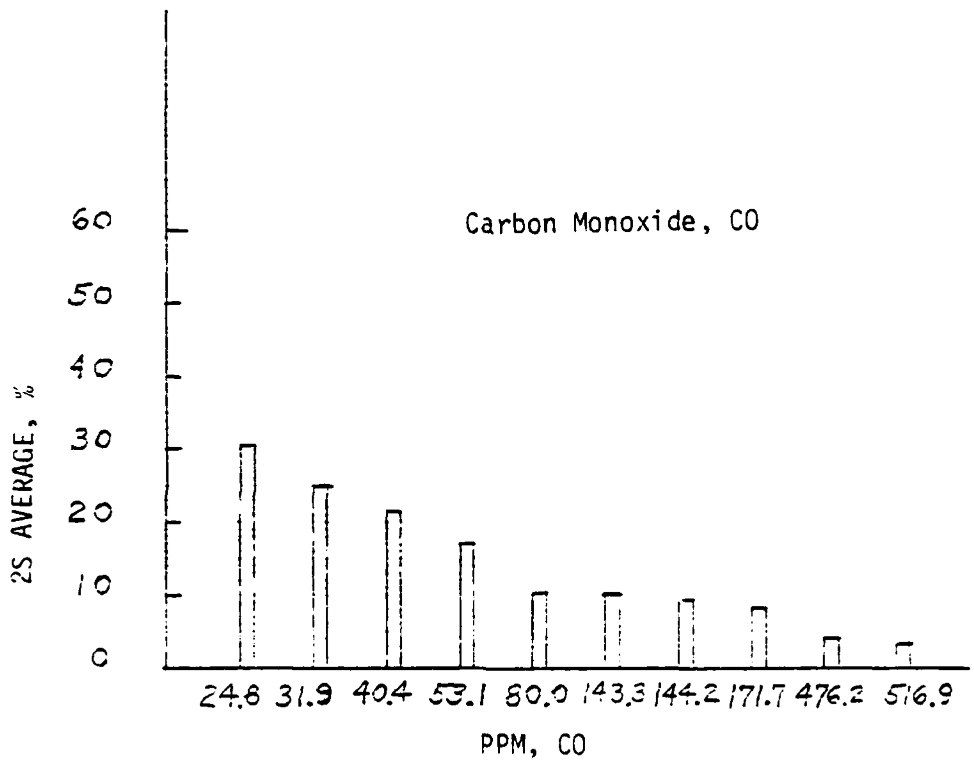


FIGURE 5B

POOLED PARTICIPANT TEST PRECISION (2S/AVERAGE)

(All Participants Except Number 7 / 4 Weeks)



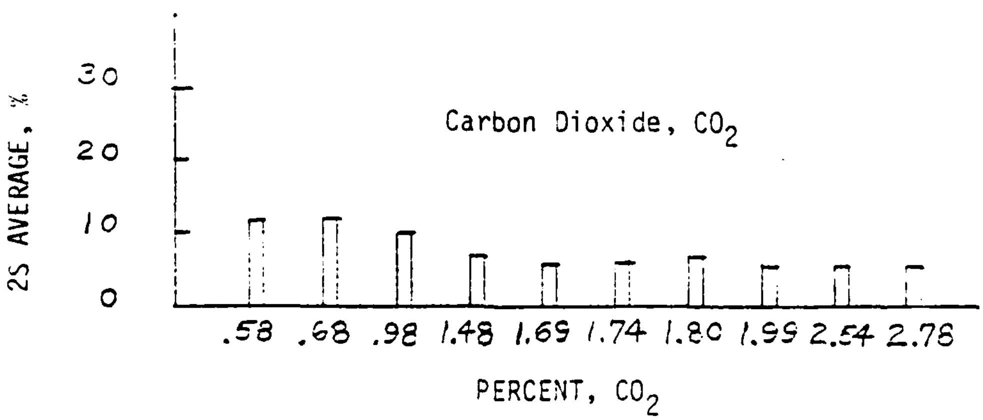
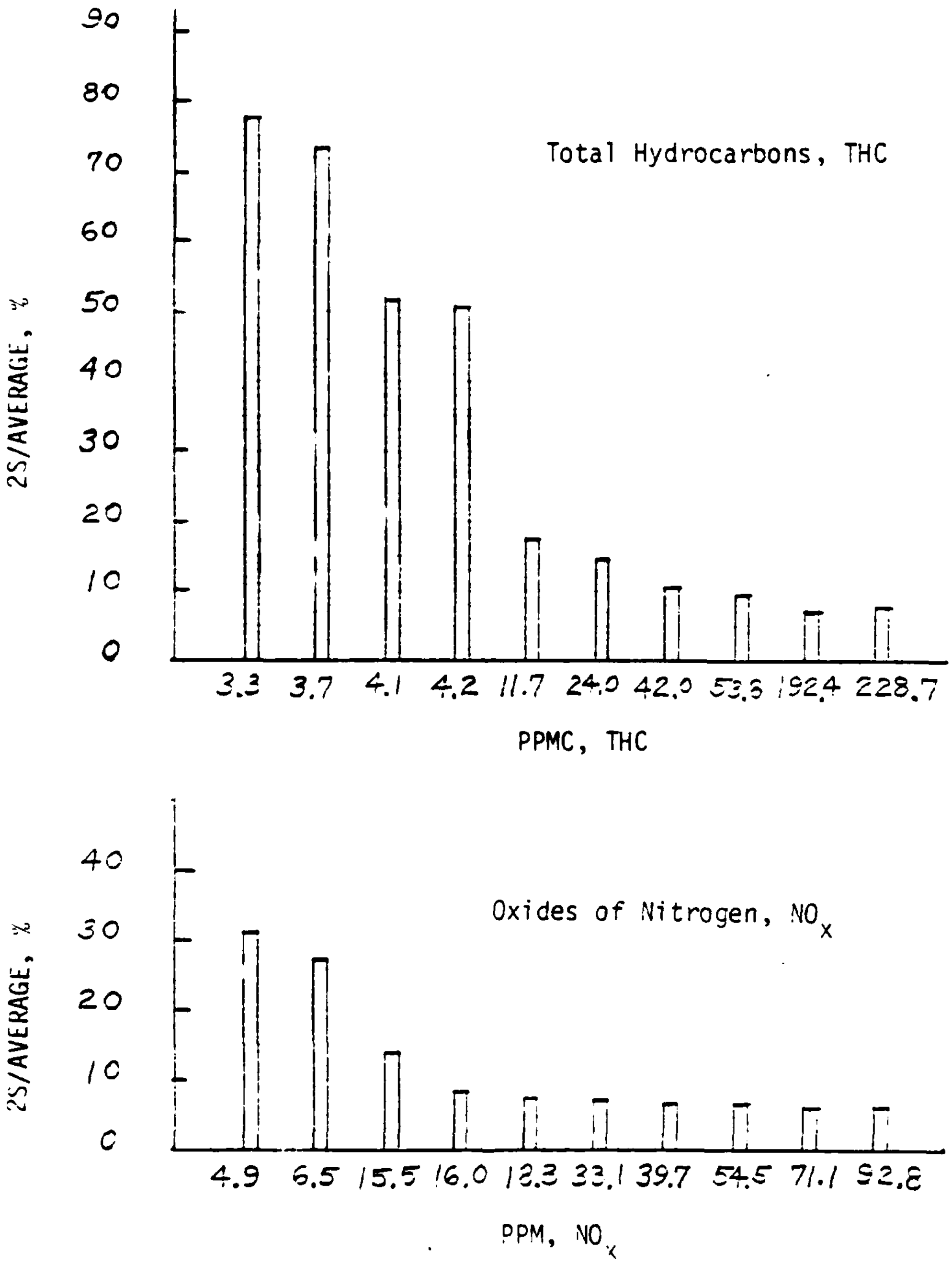


FIGURE 5B - (CONTINUED)



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APPENDIX A

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APPENDIX B

CALIBRATION GAS MEASUREMENT SUMMARY

TABLE B-I

CO_2 CALIBRATION GAS COMPARISONS (AVG./$\pm$1S)

CO_2 (Nominal = 1.49 PCT)

Test Week	Participants 1	2	3	4	5	6	7	$\overline{X}$	$2S_x$	$\overline{X}/\pm 2S_x$ Without No. 7
10-24-78	1.46 0.01	1.52 0.00	1.38* 0.01	1.47 0.02				1.483	0.0642	
10-26-78	1.45 0.00	1.52 0.00	1.52 0.01	1.47 0.01				1.490	0.0712	
10-31-78	1.46 0.00		1.47 0.01	1.52 0.00	1.50 0.01			1.487	0.0551	
11-2-78	1.45 0.00		1.48 0.01	1.50 0.00	1.48 0.01			1.477	0.0412	
11-7-78	1.47 0.01		1.48 0.00		1.49 0.01	1.55 0.00		1.497	0.0719	
11-9-78	1.43 0.00		1.50 0.01		1.47 0.01	1.50 0.01		1.475	0.0663	
11-14-78	1.49 0.01		1.47 0.01			1.50 0.00	1.43 0.01	1.472	0.0619	1.487/0.0306
11-16-78	1.47 0.01		1.46 0.00			1.46 0.01	1.55 0.01	1.485	0.0871	1.463/0.0115
3-14-79	1.49 0.02	1.52 0.01	1.51 0.01				1.63 0.01	1.537	0.1258	
3-16-79	1.50 0.03	1.54 0.02	1.54 0.00				1.48 0.01	1.515	0.0600	

* Denotes outlier.

TABLE B-I - CONTINUED

CO_2 CALIBRATION GAS COMPARISONS (AVG./±1S)

CO_2 (Nominal = 2.96 PCT)

Test Week	Participants 1	2	3	4	5	6	7	$\overline{X}$	$2S_x$	$\overline{X}/\pm 2S_x$ Without No. 7
10-24-78	2.96 0.01	2.95 0.01	2.86 0.01	2.87 0.02				2.910	0.1046	
10-26-78	2.98 0.00	2.95 0.01	2.99 0.01	2.74* 0.24				2.973	0.0416	
10-31-78	2.97 0.01		2.95 0.00	2.99 0.00	2.84 0.01			2.937	0.1340	
11-2-78	2.95 0.00		2.95 0.00	2.97 0.02	2.91 0.02			2.945	0.0503	
11-7-78	2.96 0.03		2.93 0.00		2.90 0.00	2.98 0.01		2.942	0.0700	
11-9-78	2.90 0.01		2.96 0.00		2.89 0.00	2.92 0.01		2.917	0.0620	
11-14-78	2.99 0.01		2.97 0.04			2.97 0.01	2.84 0.00	2.943	0.1380	2.977/0.0231
11-16-78	2.96 0.01		3.00 0.01			2.85 0.00	3.06 0.04	2.967	0.1769	2.937/0.1553
3-14-79	3.01 0.01	2.98 0.01	3.01 0.00				3.30 0.04	3.075	0.3013	
3-16-79	2.93 0.00	2.97 0.01	3.07 0.01				3.20 0.00	3.043	0.2408	

* Denotes outlier.

TABLE B-II

CO CALIBRATION GAS COMPARISONS
(AVG./±1S)

CO (Nominal = 34.20 ppm)

Test Week	Participants 1	2	3	4	5	6	7	$\overline{X}$	$2S_x$	$\overline{X}$/ $2S_x$ Without No. 7
10-24-78	33.85 0.06	35.10 0.29	31.50 0.14	33.63 0.17				33.520	2.988	
10-26-78	33.68 0.05	31.13 0.05	33.95 0.10	34.08 0.10				33.210	2.793	
10-31-78	34.45 0.97		31.00 0.00	35.22 0.05	34.20 0.00			33.718	3.726	
11-2-78	33.80 0.08		42.85* 0.37	31.75 0.29	34.73 0.67			33.427	3.049	
11-7-78	33.68 0.10		33.10 0.18		35.58 0.55	41.75* 4.03		34.120	2.594	
11-9-78	34.63 0.15		33.15 0.13		33.70 0.58	44.25* 0.06		33.827	1.496	
11-14-78	34.55 0.39		34.70 0.24			38.38 0.13	57.50 2.08	41.282	21.911	35.877/4.338
11-16-78	32.83 0.05		34.15 1.85			38.88 0.05	46.00 3.56	37.965	11.906	35.287/6.362
3-14-79	40.70 0.07	38.27 0.67	33.20 0.23				45.00 0.00	39.292	9.846	
3-16-79	33.78 0.22	51.65* 0.54	32.70 0.12				37.00 0.00	34.493	4.473	

* Denotes Outlier

TABLE B-II - CONTINUED

CO CALIBRATION GAS COMPARISONS
(AVG./$\pm$1S)

CO (Nominal = 444 ppm)

Test Week	Participants 1	2	3	4	5	6	7	$\overline{X}$	$2S_x$	$\overline{X}/2S_x$ Without No. 7
10-24-78	435.28 0.22	452.48 0.36	444.40 0.75	442.80 1.78				443.74	14.108	
10-26-78	431.08 0.72	443.70 0.36	445.90 0.68	442.20 0.60				440.72	13.207	
10-31-78	437.70 0.39		444.00 0.00	451.17 2.25	452.75 1.34			446.41	13.882	
11-2-78	433.70 0.34		446.63 0.15	451.43 1.56	451.18 1.05			445.74	16.642	
11-7-78	432.22 0.05		444.98 0.36		450.88 1.51	453.75 1.24		445.46	19.101	
11-9-78	435.52 0.43		445.80 0.22		449.13 0.52	455.73 0.45		446.55	16.858	
11-14-78	433.75 1.51		443.70 0.68			456.35 0.57	467.50 2.89	450.32	29.436	444.60/22.654
11-16-78	436.58 4.88		438.10 1.47			454.20 0.34	491.50 3.00	455.09	51.091	442.96/19.527
3-14-79	477.08 0.15	448.92 2.42	443.45 0.62				469.00 1.15	459.61	32.016	
3-16-79	452.63 1.45	532.04* 30.38	445.15 1.19				240.20* 0.40	448.89	10.578	

* Denotes outlier.

TABLE B-III

THC CALIBRATION GAS COMPARISONS
(AVG./±1S)

THC (Nominal = 11.97 ppmC)

Test Week	Participants 1	2	3	4	5	6	7	$\overline{X}$	$2S_x$	$\overline{X}/ 2S_x$ Without No. 7
10-24-78	21.40	21.50	10.65	13.08				16.658	11.245	
	1.01	0.41	0.1	0.13						
10-26-78	28.75	17.98	11.78	12.08				17.648	15.866	
	0.54	0.31	0.10	0.25						
10-31-78	14.68		9.00	11.68	12.38			11.935	4.678	
	0.22		0.00	0.22	0.17					
11-2-78	27.98		12.33	13.03	12.00			16.335	15.550	
	1.75		0.05	0.10	0.05					
11-7-78	14.90		9.55		12.08	10.38		11.728	4.725	
	0.18		0.06		0.05	0.05				
11-9-78	22.62		11.98		12.33	11.70		14.658	10.629	
	0.59		0.15		0.10	0.12				
11-14-78	15.38		11.63			11.10	45.20	20.828	32.719	12.703/4.666
	0.45		0.39			0.00	0.00			
11-16-78	23.78		11.48			11.50	.	15.587	14.191	15.587/14.191
	0.87		0.15			0.08	.			
3-14-79	24.30	17.14	12.13				3.30*	17.857	12.233	
	0.15	0.49	0.05				0.00			
3-16-79	41.52	14.55	12.15				4.43	18.163	32.318	
	1.06	0.09	0.44				0.05			

* Denotes outlier.

TABLE B-III - CONTINUED

THC CALIBRATION GAS COMPARISONS
(AVG./$\pm$1S)

THC (Nominal = 174.30 ppmC)

Test Week	Participants 1	2	3	4	5	6	7	$\bar{X}$	$2S_x$	$\bar{X}/2S_x$ Without No. 7
10-24-78	190.95 0.53	188.18 1.55	169.30 0.14	174.00 1.02				180.608	21.161	
10-26-78	193.50 1.90	183.98 2.44	174.33 0.19	179.00 1.23				182.703	16.412	
10-31-78	179.42 0.13		170.00 0.00	176.25 1.25	173.78 0.55			174.863	7.959	
11-2-78	189.25 2.17		174.83 0.22	178.25 0.96	172.00 0.58			178.583	15.114	
11-7-78	181.40 1.51		171.30 0.14		173.78 0.55	169.70 0.35		174.045	10.365	
11-9-78	187.25 0.50		173.10 0.08		173.25 0.50	176.23 0.71		177.458	13.371	
11-14-78	190.88 3.36		170.33 0.17			179.35 0.10	81.30 0.00	155.465	100.307	180.190/20.601
11-16-78	196.03 0.29		173.33 0.43			181.63 0.56	. .	183.663	22.972	183.660/22.972
3-14-79	195.34 1.90	179.85 0.54	172.33 0.10				56.30 0.00	150.955	127.653	
3-16-79	209.00 2.15	177.71 4.18	174.55 0.42				56.85 0.33	154.528	133.898	

* Denotes outlier.

TABLE B-IV

NO_x CALIBRATION GAS COMPARISONS (AVG./±1S)

NO_x (Nominal = 9.36 ppm)

Test Week	Participants 1	2	3	4	5	6	7	$\overline{X}$	$2S_{\overline{x}}$	$\overline{X}$/ $2S_{\overline{x}}$ Without No. 7
10-24-78	8.91 0.06	8.74 0.15	9.11 0.04	9.05 0.02				8.952	0.329	
10-26-78	8.84 0.04	8.94 0.04	8.35 0.06	9.23 0.02				8.840	0.732	
10-31-78	9.00 0.00		9.00 0.00	9.27 0.05	8.30 0.00			8.893	0.830	
11-2-78	9.28 0.04		8.98 0.10	8.83 0.10	9.30 0.00			9.098	0.461	
11-7-78	9.41 0.04		9.45 0.10		9.30 0.00	10.03 0.05		9.548	0.656	
11-9-78	9.13 0.05		3.90* 1.41		9.30 0.00	10.25 0.10		9.560	1.207	
11-14-78	9.20 0.00		9.10 0.08			10.13 0.05	8.73 0.21	9.290	1.191	9.477/1.136
11-16-78	9.48 0.02		9.45 0.06			10.15 0.06	. .	9.693	0.792	9.693/0.792
3-14-79	9.55 0.19	8.99 0.01	9.00 0.00				3.10 0.12	7.660	6.102	
3-16-79	9.73 0.02	9.05 0.02	8.75 0.06				6.45 0.19	8.500	2.847	

* Denotes Outlier.

TABLE B-IV - CONTINUED

NO_x CALIBRATION GAS COMPARISONS (AVG./±1S)

NO_x (Nominal = 107.00 ppm)

Test Week	Participants 1	2	3	4	5	6	7	$\overline{X}$	$2S_x$	$\overline{X}$/ $2S_x$ Without No. 7
10-24-78	109.75 0.31	100.80 0.14	109.80 0.26	105.38 0.81				106.432	8.577	
10-26-78	109.35 0.31	106.80 0.16	104.75 0.24	108.05 0.29				107.237	3.916	
10-31-78	109.75 0.17		108.00 0.00	108.78 1.07	111.90 0.00			109.608	3.375	
11-2-78	111.98 0.17		106.03 0.15	106.82 1.25	110.63 0.55			108.865	5.778	
11-7-78	104.65 0.13		109.73 0.25		110.90 0.00	110.98 0.30		109.065	5.997	
11-9-78	111.98 0.15		102.28 0.49		110.90 0.00	111.73 0.66		109.223	9.303	
11-14-78	111.40 0.18		108.13 0.17			113.30 0.27	90.50 0.00	105.832	20.884	110.940/5.230
11-16-78	112.00 0.12		112.48 0.15			112.00 0.42	. .	112.160	0.554	112.160/0.554
3-14-79	113.32 1.98	107.47 0.00	106.68 0.05				73.55 1.30	100.255	36.096	
3-16-79	112.05 1.94	102.57 0.24	106.63 0.25				74.45 0.30	98.925	33.545	

* Denotes outlier.

APPENDIX C

GASEOUS EXHAUST MEASUREMENT DATA

IF A DECIMAL POINT, ".", APPEARS IN THE TABLE, IT INDICATES THAT NO DATA WERE TAKEN AT THAT TEST CONDITION.

GASEOUS CONCENTRATIONS ARE GIVEN IN PPM OR PERCENT BY VOLUME.

ENGINE GASEOUS EXHAUST MEASUREMENTS

WEEK 1

DATE	PT.	PROBE	MODE	PORT 1 CO2 %	PORT 1 CO PPM	PORT 1 THC PPMC	PORT 1 NOX PPM	PORT 2 CO2 %	PORT 2 CO PPM	PORT 2 THC PPMC	PORT 2 NOX PPM	PORT 3 CO2 %	PORT 3 CO PPM	PORT 3 THC PPMC	PORT 3 NOX PPM	PORT 4 CO2 %	PORT 4 CO PPM	PORT 4 THC PPMC	PORT 4 NOX PPM
10-25	17	HIGH	1	1.71	522.2	215.7	16.1	.	527.2	244.3	16.6	1.72	522.7	227.0	16.8	1.72	507.5	221.6	17.1
10-25	18	HIGH	2	1.78	493.4	191.1	18.5	1.85	494.2	223.7	19.1	1.77	493.5	202.0	18.8	1.77	478.8	195.3	19.5
10-25	19	HIGH	3	1.94	160.6	22.2	34.8	2.03	169.3	.	34.8	1.94	158.4	24.8	34.1	1.97	164.5	24.8	35.9
10-25	20	HIGH	4	2.44	50.8	3.8	75.7	2.57	52.9	.	77.0	2.54	54.2	3.7	75.0	2.51	53.2	6.7	78.5
10-25	21	HIGH	5	2.63	40.6	3.1	95.4	2.77	39.8	.	98.9	2.79	42.5	3.3	96.9	2.73	42.1	6.4	99.8
10-25	23	HIGH	5	2.73	39.3	1.5	95.1	2.77	39.8	.	98.9	2.76	40.3	3.1	97.0	2.75	39.6	3.5	100.6
10-25	24	HIGH	4	2.48	53.5	1.8	72.4	2.54	52.9	.	71.6	2.54	55.0	3.5	73.3	2.50	54.0	3.9	75.9
10-25	25	HIGH	3	1.93	176.0	22.1	34.0	2.01	183.7	.	31.1	2.01	170.9	24.0	33.5	1.94	178.3	25.6	34.9
10-25	26	HIGH	2	1.69	474.9	178.5	18.3	1.80	470.9	.	.	1.77	473.3	192.0	18.9	1.70	460.1	187.6	18.9
10-25	27	HIGH	1	1.64	501.9	209.6	16.4	1.75	498.5	.	.	1.70	501.6	220.0	17.0	1.64	485.7	219.0	17.2
10-25	28	HIGH	1	1.65	506.6	216.5	15.1	1.78	507.5	236.0	16.6	1.73	506.7	227.0	15.0	1.73	487.3	222.7	16.0
10-25	30	HIGH	5	2.64	39.2	4.4	86.0	2.80	41.6	.	82.4	2.80	41.4	4.4	87.6	2.78	39.4	4.3	92.4
10-25	31	HIGH	4	2.38	49.8	4.0	68.0	2.55	52.6	.	61.2	2.54	53.5	2.6	68.2	2.51	50.6	5.9	71.9
10-25	32	HIGH	3	1.87	160.0	19.8	32.6	2.03	166.9	.	31.2	2.03	157.6	19.0	30.4	1.97	160.5	23.4	33.9
10-25	33	HIGH	2	1.66	489.2	192.2	17.6	1.82	457.9	.	16.6	1.82	489.4	194.0	17.3	1.67	469.6	203.0	18.6
10-25	34	HIGH	1	1.79	514.6	215.4	15.5	1.82	508.9	.	15.2	1.76	509.1	217.0	15.4	1.75	493.8	219.2	16.3
10-25	35	HIGH	2	1.82	465.4	179.4	18.0	1.86	460.3	.	16.8	1.81	462.0	185.0	17.0	1.79	447.5	183.6	18.4
10-25	36	HIGH	3	2.01	178.6	26.8	32.6	2.07	185.5	.	31.2	2.02	174.1	29.5	31.3	2.02	178.1	28.7	33.6
10-25	37	HIGH	4	2.44	52.0	2.8	71.4	2.62	52.1	.	70.7	2.56	53.1	4.4	73.1	2.56	51.3	4.4	74.5
10-25	38	HIGH	5	2.75	39.2	2.1	90.3	2.85	37.5	.	91.2	2.79	39.6	2.9	93.8	2.78	38.4	4.0	95.8
10-25	40	HIGH	1	1.77	521.2	213.6	15.9	1.81	517.6	.	15.4	1.72	517.3	229.0	16.3	1.73	500.3	216.2	16.5
10-25	41	HIGH	2	1.85	470.9	169.0	18.2	1.88	466.8	.	17.5	1.81	470.6	176.0	18.5	1.82	453.2	172.2	18.9
10-25	42	LOW	1	0.59	127.4	38.2	5.1	0.66	135.9	.	5.3	0.62	121.7	40.0	5.4	0.63	131.7	41.3	5.9
10-25	43	LOW	2	0.66	122.4	28.5	6.6	0.74	130.0	.	6.4	0.71	117.7	30.7	6.8	0.71	126.4	31.8	7.4
10-25	44	LOW	3	0.97	70.7	8.6	15.9	1.07	74.4	.	15.4	1.06	74.4	8.1	15.9	1.00	71.7	8.8	17.1
10-25	45	LOW	4	1.49	27.1	3.2	41.0	1.57	25.7	.	41.8	1.59	28.1	2.6	41.1	1.50	27.9	3.6	44.1
10-25	46	LOW	5	1.68	21.8	2.8	55.2	1.80	21.5	.	57.6	1.82	22.6	1.4	56.0	1.72	22.5	3.7	60.4
10-25	48	LOW	5	1.73	23.4	2.2	51.9	1.75	21.2	.	49.1	1.75	23.7	2.4	52.8	1.67	23.3	2.9	55.1
10-25	49	LOW	4	1.49	29.9	2.4	38.6	1.53	27.5	.	34.6	1.50	30.8	2.6	37.8	1.42	29.4	2.7	40.5
10-25	50	LOW	3	0.97	77.1	10.1	15.1	1.01	77.7	.	13.9	0.99	80.6	11.3	15.0	0.95	76.8	9.0	15.6
10-25	51	LOW	2	0.70	129.7	32.5	6.5	0.74	152.2	.	5.0	0.69	124.4	34.8	6.5	0.70	133.1	26.9	6.7
10-25	52	LOW	1	0.56	130.8	49.0	4.6	0.61	139.9	.	3.1	0.57	127.9	52.3	4.8	0.58	134.0	47.8	4.7
10-26	53	LOW	1	0.56	126.3	37.1	5.4	.	.	.	.	0.60	123.9	40.2	5.5	0.62	130.7	41.3	6.2
10-26	55	LOW	5	1.65	22.3	3.9	52.2	.	.	.	.	1.73	22.8	2.0	53.6	1.69	23.1	6.4	55.6
10-26	56	LOW	4	1.41	28.1	3.8	39.0	.	.	.	.	1.53	29.4	2.1	40.3	1.45	28.6	6.9	40.8
10-26	57	LOW	3	0.88	73.9	10.4	15.5	.	.	.	.	0.97	77.1	9.3	15.1	0.94	74.5	13.7	15.5
10-26	58	LOW	2	0.60	128.2	36.1	6.8	.	.	.	.	0.69	125.6	35.4	6.7	0.66	133.5	40.7	6.5
10-26	59	LOW	1	0.51	128.1	39.5	5.3	.	.	.	.	0.61	122.2	38.2	5.4	0.59	131.5	42.7	5.2
10-26	60	LOW	2	0.62	124.5	37.6	5.8	.	.	.	.	0.64	122.2	40.4	6.3	0.64	126.9	39.7	6.3
10-26	61	LOW	3	1.00	72.4	9.1	15.6	1.04	72.1	.	10.6	1.00	74.8	9.0	15.7	0.98	72.6	10.5	16.2
10-26	62	LOW	4	1.51	28.3	2.7	40.3	1.54	25.3	.	40.5	1.54	28.8	1.8	41.2	1.48	28.2	3.9	42.1
10-26	63	LOW	5	1.73	22.7	2.4	54.2	1.76	19.9	.	55.3	1.77	22.8	1.1	55.6	1.70	22.5	3.8	57.1
10-26	65	LOW	1	0.58	142.2	43.6	5.2	0.64	148.3	.	3.1	0.60	136.4	44.6	5.4	0.62	143.8	46.6	5.3
10-26	66	LOW	2	0.69	135.4	28.8	6.8	0.72	135.9	.	3.5	0.73	132.2	29.0	7.0	0.71	137.6	31.3	7.0

ENGINE GASEOUS EXHAUST MEASUREMENTS

WEEK 2

DATE	PT.	PROBE	MODE	PORT 1 CO2 %	PORT 1 CO PPM	PORT 1 THC PPMC	PORT 1 NOX PPM	PORT 2 CO2 %	PORT 2 CO PPM	PORT 2 THC PPMC	PORT 2 NOX PPM	PORT 3 CO2 %	PORT 3 CO PPM	PORT 3 THC PPMC	PORT 3 NOX PPM	PORT 4 CO2 %	PORT 4 CO PPM	PORT 4 THC PPMC	PORT 4 NOX PPM
10-31	125	HIGH	1	1.76	537.1	227.5	16.8	1.75	532.1	231.4	17.8	1.79	539.9	234.0	15.5	1.72	520.8	231.5	15.4
10-31	126	HIGH	2	1.77	487.1	192.9	17.9	1.85	483.3	196.3	18.9	1.80	481.9	201.0	17.0	1.74	469.6	200.8	17.1
10-31	127	HIGH	3	1.95	169.1	26.3	32.5	2.04	172.4	29.4	33.6	2.00	167.0	26.0	32.3	1.96	169.3	27.1	32.2
10-31	128	HIGH	4	2.46	50.6	3.8	69.8	2.59	49.4	7.5	73.6	2.60	49.3	3.2	72.3	2.50	49.6	4.8	70.2
10-31	129	HIGH	5	2.68	37.5	3.0	91.7	2.87	38.7	6.6	96.8	2.83	35.6	2.2	93.4	2.74	36.2	3.9	93.4
10-31	131	HIGH	5	2.57	41.2	1.9	91.3	2.88	32.2	5.8	96.8	2.83	40.5	2.3	91.0	2.86	38.5	1.9	93.3
10-31	132	HIGH	4	2.57	49.7	1.8	70.1	2.60	47.2	5.8	74.6	2.61	53.3	1.7	68.0	2.58	50.6	2.0	70.7
10-31	133	HIGH	3	2.03	167.8	19.7	33.9	2.04	169.2	23.2	34.6	2.05	161.0	20.9	32.3	2.02	169.8	20.4	32.9
10-31	134	HIGH	2	1.84	479.9	172.5	19.2	1.85	474.7	167.3	18.9	1.89	482.7	179.0	18.4	1.83	465.4	174.9	18.3
10-31	135	HIGH	1	1.76	515.0	201.4	17.1	1.80	510.2	199.4	15.7	1.80	516.9	194.0	15.9	1.77	499.3	204.5	16.0
11-01	136	HIGH	1	1.78	526.5	209.2	15.7	1.80	520.6	208.7	14.6	1.80	525.0	208.0	15.4	1.74	511.6	214.0	15.0
11-01	138	HIGH	5	2.82	40.8	3.1	89.8	2.82	37.3	5.2	94.6	2.83	42.0	5.2	97.2	2.80	40.4	7.4	91.9
11-01	139	HIGH	4	2.52	51.4	2.1	68.5	2.57	49.9	4.9	71.4	2.54	54.0	3.0	71.9	2.53	50.9	7.0	69.8
11-01	140	HIGH	3	1.97	159.3	18.8	33.6	2.00	169.8	21.2	33.5	2.02	155.1	18.0	32.5	1.97	160.0	20.6	33.5
11-01	141	HIGH	2	1.79	475.3	170.2	19.1	1.87	469.7	165.3	19.9	1.87	472.8	176.0	18.8	1.79	456.7	170.6	18.9
11-01	142	HIGH	1	1.68	529.6	230.6	16.2	1.79	522.5	223.1	16.8	1.78	529.1	234.0	16.3	1.69	507.1	225.7	16.3
11-01	143	HIGH	2	1.68	458.3	172.5	18.1	1.83	456.0	165.3	18.9	1.82	458.3	169.0	18.0	1.73	439.2	171.2	18.4
11-01	144	HIGH	3	1.90	164.3	23.6	33.7	2.03	168.5	24.7	34.6	2.03	160.7	23.2	33.2	1.95	164.0	24.3	34.2
11-01	145	HIGH	4	2.43	52.1	3.3	71.9	2.60	50.9	5.3	75.6	2.58	52.1	7.9	73.7	2.50	50.4	4.7	74.9
11-01	146	HIGH	5	2.66	38.7	2.3	93.9	2.83	35.1	4.8	97.7	2.80	40.4	1.8	95.5	2.75	37.1	3.6	99.4
11-01	148	HIGH	1	1.62	517.1	204.3	17.3	1.77	517.2	202.5	17.8	1.78	522.4	204.0	16.7	1.66	502.3	200.0	16.9
11-01	149	HIGH	2	1.74	473.2	164.0	19.7	1.88	468.7	160.1	20.9	1.89	473.9	165.0	19.2	1.77	456.9	164.0	19.8
11-01	150	LOW	1	0.57	138.7	49.4	5.3	0.60	144.0	50.6	3.1	0.61	135.8	52.6	5.3	0.60	140.3	50.7	4.9
11-01	151	LOW	2	0.67	137.8	36.4	6.9	0.73	144.7	37.2	5.2	0.71	136.2	39.4	6.9	0.69	139.1	39.4	6.6
11-01	152	LOW	3	0.95	78.3	11.4	16.0	1.02	80.4	12.9	16.7	0.99	74.7	12.2	15.7	0.95	79.1	11.6	15.9
11-01	153	LOW	4	1.44	29.7	3.7	40.8	1.51	29.3	5.0	43.9	1.54	30.9	3.7	42.3	1.42	30.1	4.6	41.1
11-01	154	LOW	5	1.63	23.5	3.2	54.0	1.70	19.9	4.1	58.5	1.78	24.1	3.0	55.2	1.65	23.8	5.8	55.1
11-01	156	LOW	5	1.61	23.9	3.0	53.4	1.71	22.0	4.6	58.5	1.76	25.0	1.8	55.1	1.60	24.2	3.8	54.5
11-01	157	LOW	4	1.39	30.1	3.0	38.5	1.50	30.3	4.9	40.7	1.54	32.0	2.8	38.7	1.40	30.5	4.7	39.0
11-01	158	LOW	3	0.88	69.8	6.9	15.4	0.99	72.9	8.7	16.7	1.01	73.3	6.8	15.2	0.94	70.3	9.2	15.2
11-01	159	LOW	2	0.64	158.7	41.5	7.0	0.75	166.8	43.4	7.3	0.73	154.1	43.3	6.9	0.71	162.2	45.9	6.8
11-01	160	LOW	1	0.51	159.3	55.9	5.3	0.62	166.3	59.9	6.2	0.62	157.4	59.2	5.3	0.61	162.9	60.9	5.2
11-02	161	LOW	1	0.54	137.7	53.5	5.0	0.57	144.8	54.2	4.1	0.57	133.0	54.5	5.1	0.57	141.1	53.9	4.4
11-02	163	LOW	5	1.67	24.2	4.0	50.4	1.67	23.0	4.3	53.4	1.70	25.5	2.5	50.4	1.61	24.7	4.9	51.3
11-02	164	LOW	4	1.43	30.8	3.5	37.8	1.49	34.3	4.9	41.9	1.50	32.7	1.7	38.2	1.39	30.9	5.6	38.8
11-02	165	LOW	3	0.90	86.7	11.1	15.4	0.97	82.4	13.4	16.7	0.98	83.6	11.6	14.9	0.91	80.3	11.9	15.1
11-02	166	LOW	2	0.52	140.5	39.3	6.9	0.71	144.5	41.3	7.3	0.71	137.4	38.1	7.0	0.67	139.3	40.0	6.5
11-02	167	LOW	1	0.52	140.5	46.5	5.3	0.60	143.1	47.5	6.2	0.58	131.8	45.5	5.5	0.56	136.3	47.7	4.8
11-02	168	LOW	2	0.60	137.4	37.1	6.7	0.68	140.6	38.2	7.3	0.65	122.7	35.6	6.6	0.65	134.7	39.8	6.3
11-02	169	LOW	3	0.97	76.5	10.7	15.4	0.98	79.7	12.4	16.7	0.98	79.6	11.4	15.4	0.90	79.8	11.6	15.8
11-02	170	LOW	4	1.50	30.0	2.7	39.5	1.49	29.7	4.6	41.8	1.51	31.7	2.6	40.3	1.38	30.0	3.9	41.6
11-02	171	LOW	5	1.70	22.6	3.3	55.3	1.73	22.4	4.4	58.5	1.74	24.5	2.3	55.5	1.59	22.7	4.1	59.1
11-02	173	LOW	1	0.58	133.2	44.0	5.3	0.62	142.3	45.5	6.2	0.58	128.4	42.4	5.5	0.56	135.9	46.2	5.2
11-02	174	LOW	2	0.67	127.6	30.2	6.8	0.69	131.5	31.0	8.3	0.69	126.0	31.0	7.4	0.65	130.4	31.4	6.8

ENGINE GASEOUS EXHAUST MEASUREMENTS

WEEK 3

DATE	PT.	PROBE	MODE	PORT 1 CO2 %	PORT 1 CO PPM	PORT 1 THC PPMC	PORT 1 NOX PPM	PORT 2 CO2 %	PORT 2 CO PPM	PORT 2 THC PPMC	PORT 2 NOX PPM	PORT 3 CO2 %	PORT 3 CO PPM	PORT 3 THC PPMC	PORT 3 NOX PPM	PORT 4 CO2 %	PORT 4 CO PPM	PORT 4 THC PPMC	PORT 4 NOX PPM
11-07	214	HIGH	1	1.78	506.8	194.9	15.9	1.79	493.6	198.3	17.8	1.77	495.7	.	17.1	1.75	487.4	199.6	15.7
11-07	215	HIGH	2	1.77	445.9	162.1	17.6	1.82	441.1	166.3	18.9	1.79	447.1	.	19.5	1.77	429.1	170.1	17.5
11-07	216	HIGH	3	1.95	176.1	23.9	32.2	2.06	179.1	26.9	34.6	2.00	194.4	.	34.7	2.01	176.9	26.7	32.2
11-07	217	HIGH	4	2.41	51.7	1.7	69.1	2.63	49.6	4.4	72.5	2.51	66.4	.	71.4	2.53	51.5	4.3	70.2
11-07	218	HIGH	5	2.63	38.7	1.2	89.1	2.88	38.0	3.5	94.7	2.76	52.7	.	92.7	2.77	38.4	4.2	91.6
11-07	220	HIGH	5	2.56	38.5	0.9	88.8	2.86	34.9	3.6	93.7	2.72	52.3	.	94.3	2.81	38.3	2.2	91.0
11-07	221	HIGH	4	2.40	51.5	1.0	67.5	2.62	49.8	3.6	70.4	2.48	65.6	.	73.0	2.56	51.6	2.7	68.5
11-07	222	HIGH	3	1.88	165.5	17.8	32.1	2.05	168.4	20.7	33.6	1.95	184.1	.	38.6	2.00	167.2	20.4	32.0
11-07	223	HIGH	2	1.70	478.9	168.4	18.3	1.88	470.7	168.4	19.9	1.79	478.3	.	19.5	1.82	462.4	178.3	18.1
11-07	224	HIGH	1	1.63	523.5	212.8	15.8	1.77	512.9	205.6	16.8	1.72	518.6	.	17.7	1.73	505.2	221.9	15.7
11-08	225	HIGH	1	1.77	519.9	214.4	14.6	1.75	515.8	211.8	15.7	1.86	511.0	241.4	15.9	1.71	505.8	215.6	15.1
11-08	227	HIGH	5	2.74	40.7	.	82.9	2.80	41.2	4.6	90.4	2.92	53.1	3.8	87.0	2.74	41.5	4.9	88.1
11-08	228	HIGH	4	2.43	51.6	1.8	62.8	2.55	50.7	4.6	68.3	2.63	65.1	4.1	66.5	2.46	52.2	2.6	66.7
11-08	229	HIGH	3	1.93	161.2	18.4	30.8	1.99	166.2	20.7	32.4	2.09	179.8	23.1	31.4	1.94	163.2	20.1	32.1
11-08	230	HIGH	2	1.72	510.3	198.0	16.8	1.79	504.0	195.2	17.8	1.92	506.2	212.4	17.6	1.75	491.2	197.9	17.8
11-08	231	HIGH	1	1.62	550.1	249.3	14.6	1.75	544.7	247.9	15.7	1.85	542.9	271.5	15.7	1.66	529.7	247.3	15.6
11-08	232	HIGH	2	1.66	509.0	207.6	16.7	1.80	504.0	200.4	17.8	1.92	501.0	219.7	18.1	1.74	489.7	205.1	17.9
11-08	233	HIGH	3	1.82	166.9	24.7	30.3	1.99	171.5	24.3	32.4	2.11	184.0	25.6	32.0	1.90	168.7	26.2	31.7
11-08	234	HIGH	4	2.30	53.0	3.5	66.1	2.54	50.7	4.4	66.2	2.66	65.2	2.2	68.2	2.53	51.4	2.7	70.0
11-08	235	HIGH	5	2.77	39.7	2.6	85.1	2.77	36.0	3.6	92.5	2.87	52.1	1.9	88.0	2.76	38.3	1.7	90.1
11-08	237	HIGH	1	1.69	525.3	238.7	14.3	1.71	522.5	234.5	16.8	1.81	519.5	253.9	15.3	1.68	501.1	242.6	15.7
11-08	238	HIGH	2	1.76	491.0	207.8	16.0	1.79	486.9	204.5	17.8	1.90	487.7	220.7	17.1	1.76	469.6	210.6	17.5
11-08	239	LOW	1	0.56	140.5	54.4	4.9	0.60	144.8	53.7	6.2	0.64	156.0	57.2	5.1	0.60	143.5	53.7	4.9
11-08	240	LOW	2	0.61	132.2	40.1	5.9	0.67	139.1	41.3	7.3	0.69	148.5	43.5	6.1	0.66	135.5	41.6	6.0
11-08	241	LOW	3	0.91	83.8	14.0	14.8	0.98	85.6	14.5	15.6	1.03	96.3	14.6	15.4	0.95	84.2	15.1	15.2
11-08	242	LOW	4	1.40	32.8	4.0	37.5	1.48	34.5	5.1	39.7	1.49	44.7	3.9	39.0	1.43	33.0	5.1	38.9
11-08	243	LOW	5	1.60	24.4	3.5	51.4	1.69	21.9	4.5	54.4	1.73	35.7	3.3	54.6	1.66	24.8	5.3	54.2
11-08	245	LOW	5	1.57	24.8	3.2	50.0	1.68	23.0	4.4	53.4	1.70	36.8	2.8	52.9	1.64	25.2	5.3	53.3
11-08	246	LOW	4	1.34	32.0	3.3	35.7	1.47	31.2	4.5	38.6	1.56	44.1	2.8	38.2	1.41	32.0	5.5	37.3
11-08	247	LOW	3	0.84	72.1	7.9	14.3	0.96	76.0	9.3	15.6	1.04	83.5	7.9	16.0	0.93	72.1	10.4	14.9
11-08	248	LOW	2	0.55	156.5	44.2	6.3	0.70	163.6	46.5	8.3	0.74	172.7	47.6	7.4	0.68	157.8	48.1	6.5
11-08	249	LOW	1	0.43	154.9	64.4	4.5	0.57	158.8	67.1	5.2	0.59	172.5	69.4	5.7	0.56	157.1	65.6	4.5
11-09	250	LOW	1	0.53	133.1	50.1	2.6	0.57	139.0	50.6	3.1	0.58	151.8	58.8	5.4	0.57	135.7	52.2	4.8
11-09	252	LOW	5	1.68	23.2	2.1	51.5	1.68	21.4	4.3	57.5	1.72	35.6	6.6	57.3	1.62	23.5	4.2	56.4
11-09	253	LOW	4	1.47	30.6	2.0	36.5	1.46	29.7	4.1	40.7	1.52	44.2	7.3	39.4	1.41	30.5	4.8	40.2
11-09	254	LOW	3	0.93	77.1	9.1	12.2	0.98	82.9	11.1	16.7	1.01	90.4	11.6	15.9	0.93	75.9	12.9	16.0
11-09	255	LOW	2	0.61	138.7	37.7	3.8	0.68	142.8	39.8	7.3	0.71	155.8	42.1	6.5	0.66	137.6	38.4	6.4
11-09	256	LOW	1	0.49	135.4	54.9	2.3	0.58	141.1	56.3	5.2	0.58	149.9	58.4	4.9	0.54	134.3	54.1	4.7
11-09	257	LOW	2	0.58	135.6	41.2	3.5	0.68	149.3	42.4	7.3	0.68	148.8	44.3	6.4	0.63	134.7	40.6	6.1
11-09	258	LOW	3	0.91	78.9	10.4	13.6	0.98	79.7	11.8	17.7	1.02	88.5	11.7	16.8	0.93	75.8	10.5	16.4
11-09	259	LOW	4	1.40	31.9	2.5	38.7	1.48	28.6	4.5	42.8	1.52	44.5	3.3	41.9	1.41	29.6	2.9	42.2
11-09	260	LOW	5	1.61	25.9	2.3	53.3	1.71	21.3	4.2	58.5	1.74	36.1	3.0	56.8	1.61	23.6	3.0	57.8
11-09	262	LOW	1	0.48	135.0	50.2	2.2	0.58	139.0	50.6	6.2	0.60	148.5	52.8	5.3	0.57	137.0	48.6	4.9
11-09	263	LOW	2	0.58	137.6	39.3	3.7	0.69	145.0	39.3	7.3	0.70	154.8	41.8	6.5	0.66	139.4	38.3	6.4

ENGINE GASEOUS EXHAUST MEASUREMENTS

WEEK 4

DATE	PT.	PROBE	MODE	PORT 1 CO2 %	PORT 1 CO PPM	PORT 1 THC PPMC	PORT 1 NOX PPM	PORT 2 CO2 %	PORT 2 CO PPM	PORT 2 THC PPMC	PORT 2 NOX PPM	PORT 3 CO2 %	PORT 3 CO PPM	PORT 3 THC PPMC	PORT 3 NOX PPM	PORT 4 CO2 %	PORT 4 CO PPM	PORT 4 THC PPMC	PORT 4 NOX PPM
11-15	308	HIGH	1	1.75	517.4	200.2	15.5	1.50	533.0	.	8.5	1.77	520.2	238.5	16.7	1.81	497.3	215.9	16.3
11-15	309	HIGH	2	1.73	455.0	171.3	17.4	1.48	470.0	72.3	11.0	1.79	462.5	196.0	18.8	1.83	436.8	178.5	18.3
11-15	310	HIGH	3	1.90	179.3	25.0	32.8	1.67	210.0	23.8	29.0	2.00	198.2	35.3	34.7	2.04	179.4	29.4	34.1
11-15	311	HIGH	4	2.56	51.0	1.6	71.5	2.15	67.0	15.8	70.5	2.57	60.0	4.1	73.3	2.61	51.2	6.1	76.6
11-15	312	HIGH	5	2.75	37.5	1.7	93.0	3.35	47.0	13.7	95.5	2.84	45.4	2.8	95.7	2.87	37.3	2.8	101.0
11-15	314	HIGH	5	2.81	39.1	1.6	91.5	2.29	47.0	10.8	102.0	2.83	46.0	3.8	95.9	2.92	38.1	1.8	98.9
11-15	315	HIGH	4	2.56	49.5	1.7	70.0	2.06	65.0	10.6	71.0	2.57	59.1	3.8	73.1	2.67	49.8	1.6	75.0
11-15	316	HIGH	3	1.97	155.1	16.0	33.2	1.58	183.0	12.9	33.0	2.03	174.8	18.9	34.9	2.10	158.5	16.5	35.0
11-15	317	HIGH	2	1.80	499.0	179.1	18.6	1.45	489.0	59.7	17.0	1.86	513.1	188.7	20.5	1.93	488.1	191.8	20.0
11-15	318	HIGH	1	1.68	563.1	260.0	15.5	1.35	543.0	82.8	12.0	1.76	569.8	276.0	17.4	1.81	550.3	273.8	17.0
11-15	319	HIGH	1	1.71	506.3	211.5	15.1	1.43	533.0	65.2	4.5	1.73	508.5	237.4	15.6	1.79	489.9	226.1	15.9
11-15	321	HIGH	5	2.64	38.8	2.2	88.0	2.35	68.0	4.5	104.0	2.79	47.3	6.3	89.3	2.84	39.0	3.5	93.1
11-15	322	HIGH	4	2.53	52.1	2.0	68.7	2.11	83.0	4.0	78.5	2.55	61.3	6.2	69.7	2.59	52.3	3.9	72.3
11-15	323	HIGH	3	1.94	177.1	24.6	31.8	1.63	215.0	10.6	33.0	1.98	195.3	27.5	33.1	2.02	176.7	28.4	33.3
11-15	324	HIGH	2	1.72	495.8	203.3	17.2	1.46	520.0	68.5	14.3	1.79	509.7	230.1	18.2	1.82	474.9	210.0	18.5
11-15	325	HIGH	1	1.60	525.6	237.5	14.9	1.38	528.0	75.9	12.5	1.70	525.6	256.2	16.4	1.70	504.8	250.6	16.3
11-15	326	HIGH	2	1.66	496.1	209.3	17.0	1.45	492.0	68.6	14.0	1.79	498.7	223.9	18.6	1.81	475.8	220.2	18.0
11-15	327	HIGH	3	2.02	181.9	30.8	31.4	1.58	200.0	18.1	33.0	1.95	199.6	34.8	33.1	2.03	184.0	32.6	33.5
11-15	328	HIGH	4	2.57	52.5	3.0	68.2	2.03	55.0	6.3	80.5	2.50	61.9	3.2	69.2	2.58	52.6	3.0	73.6
11-15	329	HIGH	5	2.85	39.5	1.4	88.0	2.28	42.0	5.5	105.0	2.76	47.6	2.1	90.5	2.84	39.2	1.9	95.4
11-15	331	HIGH	1	1.88	539.3	243.1	15.0	1.42	513.0	77.5	15.9	1.67	536.9	260.3	15.7	1.74	523.2	264.4	16.5
11-15	332	HIGH	2	2.02	497.0	201.0	17.0	1.51	478.0	67.0	15.5	1.78	500.3	213.5	17.8	1.84	481.3	218.7	18.8
11-16	333	LOW	1	0.55	142.5	63.8	5.0	0.62	158.0	19.9	2.5	0.58	160.5	71.9	5.1	0.60	146.8	66.3	4.6
11-16	334	LOW	2	0.59	142.0	61.2	5.9	0.67	155.0	19.5	3.8	0.61	162.4	69.4	6.0	0.65	146.5	63.1	5.5
11-16	335	LOW	3	0.94	87.2	16.8	15.9	0.96	90.0	6.0	11.5	0.98	98.4	19.8	15.8	0.99	88.7	17.7	15.4
11-16	336	LOW	4	1.39	32.6	6.3	39.1	1.39	33.0	3.6	33.6	1.49	41.3	5.7	37.9	1.48	33.5	6.7	38.8
11-16	337	LOW	5	1.72	24.4	6.2	54.3	1.59	29.0	3.3	47.8	1.67	32.2	5.5	52.4	1.71	25.3	6.7	54.4
11-16	339	LOW	5	1.72	25.2	6.2	52.9	1.59	35.0	3.6	48.0	1.67	30.9	5.5	52.0	1.70	25.9	6.8	52.8
11-16	340	LOW	4	1.49	31.3	5.6	38.5	1.39	45.0	3.7	33.6	1.48	37.9	5.0	37.0	1.48	31.8	5.9	37.8
11-16	341	LOW	3	1.00	75.1	9.6	15.6	0.95	95.0	6.0	12.0	0.97	84.4	9.8	15.1	0.98	76.1	10.4	15.0
11-16	342	LOW	2	0.69	157.4	49.1	6.7	0.71	170.0	17.3	5.0	0.68	173.6	52.4	6.7	0.71	160.6	51.0	6.2
11-16	343	LOW	1	0.61	156.6	60.7	5.3	0.64	162.0	20.7	3.7	0.58	174.8	65.6	5.4	0.62	160.1	62.9	4.8
11-16	344	LOW	1	0.54	143.2	61.4	5.1	0.66	173.0	16.9	3.5	0.59	162.1	72.3	4.9	0.60	146.8	64.5	4.5
11-16	346	LOW	5	1.61	25.7	6.2	52.9	1.70	30.0	2.7	53.0	1.67	31.5	6.4	51.5	1.70	26.0	7.3	52.1
11-16	347	LOW	4	1.36	32.7	5.7	39.5	1.48	40.0	2.4	38.5	1.49	39.3	5.4	38.5	1.45	32.8	6.9	38.4
11-16	348	LOW	3	0.87	87.8	15.1	16.1	1.06	103.0	8.5	14.3	0.99	96.1	16.4	15.6	0.97	88.2	17.3	15.2
11-16	349	LOW	2	0.68	146.7	48.7	6.9	0.76	160.0	14.3	5.4	0.70	164.3	55.8	6.6	0.69	149.8	50.8	6.1
11-16	350	LOW	1	0.58	143.5	57.8	4.4	0.66	145.0	17.7	4.3	0.59	161.7	66.0	4.9	0.59	146.2	61.2	4.6
11-16	351	LOW	2	0.78	147.1	50.9	6.0	0.76	143.0	17.0	5.1	0.70	165.3	57.0	6.8	0.70	149.9	53.0	6.3
11-16	352	LOW	3	1.23	86.5	15.4	15.5	1.02	68.0	9.2	14.7	0.99	98.4	18.0	15.5	0.98	87.2	15.8	15.5
11-16	353	LOW	4	1.64	32.3	5.2	40.2	1.49	.	5.3	41.5	1.49	39.9	6.2	39.6	1.49	32.3	5.1	40.0
11-16	354	LOW	5	1.71	25.4	5.3	55.4	1.70	.	4.7	58.7	1.68	32.3	5.8	53.5	1.70	25.1	5.2	55.1
11-16	356	LOW	1	0.60	162.3	63.5	5.0	0.71	165.0	21.2	5.5	0.60	179.7	71.7	5.1	0.63	164.5	67.4	5.3
11-16	357	LOW	2	0.71	164.4	54.3	6.4	0.80	157.0	18.4	5.2	0.69	182.9	62.7	6.7	0.71	166.2	58.0	6.7

ENGINE GASEOUS EXHAUST MEASUREMENTS

WEEK 5

DATE	PT.	PROBE	MODE	PORT 1				PORT 2				PORT 3				PORT 4			
				CO2 %	CO PPM	THC PPMC	NOX PPM	CO2 %	CO PPM	THC PPMC	NOX PPM	CO2 %	CO PPM	THC PPMC	NOX PPM	CO2 %	CO PPM	THC PPMC	NOX PPM
03-14	402	HIGH	1	1.76	524.7	231.7	14.3	2.04	565.0	74.5	1.6	1.82	528.5	241.1	15.7	1.82	529.0	252.6	14.1
03-14	403	HIGH	2	1.77	489.5	201.7	16.1	2.06	512.5	64.3	1.6	1.87	493.6	204.7	17.4	1.87	493.0	213.4	16.1
03-14	404	HIGH	3	2.13	181.2	29.0	31.8	2.34	227.5	10.2	28.0	2.10	206.3	31.9	28.2	2.12	187.5	33.5	33.3
03-14	405	HIGH	4	2.64	55.0	4.6	67.3	2.96	95.0	5.9	51.0	2.64	63.9	3.7	66.1	2.67	60.5	7.2	69.5
03-14	406	HIGH	5	2.90	41.0	3.9	87.2	3.18	65.3	.	73.0	2.89	47.6	2.5	85.4	2.89	46.1	5.9	90.2
03-14	408	HIGH	5	2.85	38.8	1.9	85.5	3.14	67.5	5.2	81.0	2.85	45.9	1.5	84.5	2.88	46.1	2.0	88.9
03-14	409	HIGH	4	2.59	52.0	1.9	65.0	2.84	76.0	1.0	47.0	2.63	60.7	1.3	64.4	2.66	59.2	2.2	67.2
03-14	410	HIGH	3	2.04	165.9	19.0	30.5	2.20	202.5	6.2	2.2	2.08	174.3	18.8	30.5	2.08	174.4	21.2	31.2
03-14	411	HIGH	2	1.83	475.3	178.3	16.9	1.94	456.0	50.9	1.5	1.87	479.4	181.1	18.1	1.87	481.7	187.2	17.3
03-14	412	HIGH	1	1.80	546.3	233.1	14.6	1.80	505.0	65.5	1.2	1.83	547.9	238.9	16.5	1.84	551.7	247.3	14.7
03-15	413	HIGH	1	1.68	551.4	272.6	14.8	1.88	565.0	94.3	4.2	1.71	552.5	277.0	17.3	1.69	557.2	288.9	15.0
03-15	415	HIGH	5	2.68	46.7	3.3	82.8	3.08	77.5	5.7	88.0	2.72	55.2	4.6	86.1	2.71	52.4	3.8	90.2
03-15.	416	HIGH	4	2.44	61.9	2.9	62.6	2.78	97.5	5.5	71.0	2.48	67.6	4.3	64.7	2.45	69.7	2.6	67.6
03-15	417	HIGH	3	1.93	180.9	26.0	30.9	2.12	222.5	12.1	14.0	1.97	198.7	28.0	32.0	1.94	189.3	28.2	32.3
03-15	418	HIGH	2	1.76	557.5	247.2	17.2	1.90	557.5	78.1	6.7	1.81	539.8	255.8	19.7	1.77	559.6	267.8	17.5
03-15	419	HIGH	1	1.70	615.0	350.4	14.8	1.81	605.0	115.0	5.3	1.68	604.2	351.9	17.1	1.67	621.7	362.1	13.4
03-15	420	HIGH	2	1.77	563.7	279.1	16.7	1.88	565.0	100.0	6.0	1.72	558.7	280.2	18.6	1.74	571.4	290.9	14.4
03-15	421	HIGH	3	1.96	192.4	34.6	30.2	2.06	225.0	16.2	14.0	1.91	211.2	34.2	30.3	1.93	202.4	38.6	28.5
03-15	422	HIGH	4	2.48	63.8	4.3	64.4	2.64	155.0	6.8	84.0	2.43	66.2	3.8	64.2	2.47	71.4	4.9	66.6
03-15	423	HIGH	5	2.71	47.3	2.9	83.8	2.92	65.0	6.0	109.0	2.67	51.5	2.3	83.6	2.69	71.3	3.5	87.4
03-15	425	HIGH	1	1.65	557.1	283.0	15.0	1.74	522.5	.	8.5	1.66	554.4	287.0	16.8	1.63	562.0	301.4	14.9
03-15	426	HIGH	2	1.76	527.4	244.5	17.0	1.84	490.0	.	7.0	1.76	521.9	287.0	18.7	1.73	533.1	261.7	14.9
03-15	427	LOW	1	0.52	140.0	66.1	4.7	0.57	164.0	.	3.5	0.56	146.6	67.4	4.7	0.55	147.4	73.6	4.4
03-15	428	LOW	2	0.67	153.7	53.5	6.3	0.72	176.0	.	4.0	0.69	164.0	55.1	6.5	0.68	161.0	59.4	6.0
03-15	429	LOW	3	0.97	92.8	17.4	15.1	1.02	114.0	7.0	8.8	0.96	97.9	17.3	14.9	0.95	96.3	19.6	15.1
03-15	430	LOW	4	1.49	37.1	3.8	37.2	1.51	57.0	2.5	9.1	1.45	41.9	3.6	36.7	1.43	43.2	4.8	39.2
03-15	431	LOW	5	1.68	27.3	3.1	51.4	1.74	45.0	2.5	28.0	1.65	31.6	3.0	50.9	1.63	32.7	3.4	54.9
03-15	433	LOW	5	1.64	28.6	2.5	50.5	1.72	46.0	2.5	33.0	1.65	36.2	2.9	49.6	1.64	34.9	3.6	50.4
03-15	434	LOW	4	1.42	37.3	2.7	36.3	1.46	57.0	2.5	10.0	1.45	45.0	2.9	35.7	1.42	44.5	4.0	35.7
03-15	435	LOW	3	0.95	86.9	12.2	14.8	0.98	107.0	5.5	9.1	0.95	95.6	12.8	14.6	0.95	92.2	14.4	13.2
03-15	436	LOW	2	0.64	161.3	52.2	6.3	0.69	175.0	17.9	3.9	0.68	174.9	54.2	6.4	0.67	170.5	58.6	4.8
03-15	437	LOW	1	0.53	153.5	71.0	4.8	0.60	150.0	23.4	3.0	0.56	165.6	73.1	4.9	0.56	161.8	80.5	3.7
03-16	438	LOW	1	0.54	154.5	67.8	4.9	0.64	194.0	22.1	5.9	0.59	176.3	69.8	5.6	0.57	160.3	71.0	4.6
03-16	440	LOW	5	1.65	28.3	3.3	50.3	1.84	82.0	3.5	18.0	1.68	35.9	4.8	51.8	1.64	27.6	4.5	53.6
03-16	441	LOW	4	1.42	34.8	3.1	36.4	1.60	97.0	3.0	13.0	1.45	43.4	4.6	37.1	1.40	34.2	4.7	37.5
03-16	442	LOW	3	0.93	78.1	8.4	14.8	1.08	160.0	5.0	8.7	0.99	84.9	10.3	15.3	0.94	76.8	10.7	13.8
03-16	443	LOW	2	0.67	150.0	49.0	6.9	0.80	201.0	16.6	8.9	0.72	158.6	51.4	7.4	0.69	155.8	52.8	5.0
03-16	444	LOW	1	0.52	140.6	61.1	4.9	0.64	173.0	21.1	7.0	0.58	139.1	64.1	5.4	0.55	145.8	65.4	3.9
03-16	445	LOW	2	0.62	145.3	47.9	6.4	0.72	169.0	18.1	9.2	0.68	162.9	51.0	6.7	0.63	150.8	53.2	5.3
03-16	446	LOW	3	0.92	90.5	16.6	14.8	1.07	109.0	8.6	9.7	0.95	91.9	18.7	15.3	0.92	90.8	18.4	12.5
03-16	447	LOW	4	1.43	36.4	3.7	38.6	1.56	51.0	4.5	13.0	1.47	36.2	5.7	39.8	1.41	34.6	4.1	38.6
03-16	448	LOW	5	1.64	28.3	3.2	51.8	1.76	43.0	4.3	23.0	1.67	27.5	5.4	53.5	1.63	26.8	4.0	53.3
03-16	450	LOW	1	0.53	144.8	55.6	5.2	0.63	146.0	19.9	8.0	0.59	148.3	59.2	5.3	0.57	149.6	60.6	4.7
03-16	451	LOW	2	0.61	143.5	43.6	6.5	0.72	137.0	16.9	10.0	0.68	144.5	46.3	6.7	0.65	148.3	47.0	5.0

APPENDIX D

ENGINE SMOKE MEASUREMENTS

IF A DECIMAL POINT, ".", APPEARS IN THE TABLE, IT INDICATES THAT NO DATA WERE TAKEN AT THAT TEST CONDITION.

APPENDIX D

ENGINE SMOKE MEASUREMENTS

(SAE SMOKE NUMBER)

Week	Pt.	Probe	Mode	Port 1	Port 2	Port 3	Port 4
1	84	High	3	62.2	.	70.0	74.1
1	85	High	5	74.3	.	80.0	73.6
1	87	High	5	71.5	.	70.0	80.4
1	88	High	3	63.4	.	0.0	79.3
1	91	High	5	70.3	.	82.0	84.9
1	92	High	3	64.3	.	72.0	81.4
1	94	High	3	61.4	.	70.0	71.6
1	95	High	5	68.7	.	82.0	79.1
1	97	Low	3	55.7	.	61.0	71.4
1	98	Low	5	69.4	.	77.0	84.2
1	100	Low	5	70.7	.	77.0	81.4
1	101	Low	3	55.2	.	60.0	58.9
1	104	Low	5	68.9	.	79.0	75.7
1	105	Low	3	56.2	.	65.0	57.7
1	107	Low	3	58.5	.	56.0	60.6
1	108	Low	5	68.2	.	79.0	83.5
2	191	Low	1	29.7	28.5	27.0	28.5
2	192	Low	2	35.4	39.0	39.0	37.4
2	193	Low	3	55.6	61.0	60.0	59.0
2	195	Low	3	56.9	67.0	62.0	74.9
2	196	Low	2	30.3	35.1	34.0	39.3
2	197	Low	1	22.9	23.3	.	26.3
3	280	Low	1	25.2	23.7	26.5	28.4
3	281	Low	2	31.8	32.6	36.8	37.2
3	282	Low	3	55.7	60.0	60.2	59.6
3	284	Low	3	55.7	61.4	61.5	73.5
3	285	Low	2	38.5	36.4	35.7	45.5
3	286	Low	1	26.1	29.4	30.5	30.1
3	288	Low	3	55.2	64.7	61.1	66.8
3	289	Low	2	30.3	34.8	36.8	38.2
3	290	Low	1	23.7	28.7	28.8	29.4
3	291	Low	2	32.6	38.3	37.8	37.9

Week	Pt.	Probe	Mode	Port 1	Port 2	Port 3	Port 4
4	374	Low	1	39.3	51.4	39.6	45.5
4	375	Low	2	42.5	50.6	46.9	45.5
4	376	Low	3	59.9	77.4	65.0	60.7
4	378	Low	3	58.4	74.6	63.3	63.1
4	379	Low	2	32.7	47.3	37.8	39.2
4	380	Low	1	25.9	38.4	29.2	28.4
4	382	Low	3	57.4	75.8	64.1	68.2
4	383	Low	2	33.4	48.3	38.6	45.2
4	384	Low	1	25.5	37.5	28.3	25.9
4	385	Low	2	34.2	49.6	40.0	37.9
5	468	Low	1	24.3	.	.	24.2
5	469	Low	2	33.9	.	.	35.9
5	470	Low	3	56.3	.	.	59.0
5	472	Low	3	59.3	.	.	59.5
5	473	Low	2	33.4	.	.	36.2
5	474	Low	1	26.2	.	.	30.0
5	476	Low	3	56.9	.	.	63.2
5	477	Low	2	39.8	.	.	43.7
5	478	Low	1	30.7	.	.	34.0
5	479	Low	2	36.6	.	.	39.7

END

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